MAKARA 2019

CONGRESO INTERNACIONAL cambio climático EN COSTAS Y MONTAÑAS DE AMÉRICA

CAPITULO 9

ANALYSIS OF FEASIBILITY IN THE APPLICATION OF A HYBRID (SMALL HYDRO POWER-SOLAR) POWER PRODUCTION SYSTEM IN COLOMBIA: A CASE STUDY.

Andrés Mauricio Joya Delgado [a]
Orlando Celso Longo[b]
& Luciane Ferreira Alcoforado[c]
a Pos-Civil Master's Degree student, Universidade Federal Fluminense, Niterói, RJ. 24210-240, BRASIL. andresjoya@protonmail.com
b Dean on the faculty of Civil Engineering of Universidade Federal Fluminense, Niterói, RJ. 24210-240, BRASIL. orlandolongo@gmail.com.
c Teacher on the faculty of Civil Engineering of Universidade Federal Fluminense, Niterói, RJ. 24210-240, BRASIL. lucianea@id.uff.br.

Por: Andrés Mauricio Joya Delgado
Orlando Celso Longo
Luciane Ferreira Alcoforado

Abstract. The excessive use of non-renewable energy sources is generating considerable changes in the global climate and increasing temperature of the Earth. A change of 2°C can generate major natural disasters such as floods, dwindling water resources, reducing the area of glaciers, affecting ecosystems and agriculture. The use of renewable sources such as Small Hydro Power and solar energy will contribute to reduce greenhouse gas emissions.

This study proposes the design of a hybrid power generation system that can power a house with average energy consumption in the mountainous areas of Colombia. A feasibility study will also be conducted where the fundamental aspects of the proposed system are analyzed in detail. For this analysis a case study is established, with the idea of expanding the particularity of this study to the general field of application in Colombia. The Small Hydro Power systems represent a very attractive alternative in terms of cost and performance as they are considered robust systems.

The functional, technical and economic viability of this technology is demonstrated in this paper. A detailed analysis of the legal framework (Law 1715 of 2014) was carried out. The implementation of this hybrid production system can be seen as a source of profit in the Colombian context. It shows that entrepreneurs can benefit from the energy production. According to the data obtained, an 2243 USD investment can be used to eliminate the energy bill for at least 10 years. This value will be recovered after **9.78** years. It is a way in which people obtain energy autonomy due to the consumer becomes a producer. This situation transforms the paradigm of relationship between people and companies that provide services. Finally, challenges and possibilities were reviewed. Another objective of this work is to publicize the benefits offered by the legislation on those interested in installing renewable energy generation systems. It is important to increase the knowledge on renewable energy sources and its implementation.

Keywords: Hydroelectric power, Small scale Hydro, Solar energy, Hybrid system, Decentralization of energy Production, Energy autonomy.

Acknowledgment. The Autor Andres Joya thanks the master Orlando for his guidance, support and great capacity to share knowledge. The authors gratefully acknowledge the support of the Program de Pos-CIVIL of Universidade Federal Fluminense (UFF), Niterói RJ, Brasil. This work was supported in part by the brazilian government through CAPES foundation (A Coordenaçâo de Aperfeiçoamento de Pessoal de nível superior).

Introduction. Currently, there are being generated significant changes in the global climate and temperature of the earth. It is caused due to the excessive use of non-renewable energy sources (Houghton et al 2001). The increase in greenhouse gases generated by human activity is accelerating this climate change. The burning of fossil fuels increases the amount of CO2 in the atmosphere. The problem is that this type of fuels is the main source of energy for humans. A 2°C increase could generate major natural disasters within a short and medium term (Stanford et al 2014). It could produce floods, decrease of water resources, defrosting of glaciers, destruction of ecosystems and biodiversity with strong impacts on agriculture. The knowledge in renewable energy sources like hydropower must be improved to preserve the environment.

The generation of **small-scale hydroelectric power (SHP** onwards) represents an interesting alternative with proven performance. They are considered low cost and tough systems that require minimal maintenance with average durability of 50 years (Paish 2002).

This kind of energy production is one of the most economically effective ways to electrify rural areas. For faraway places of the national grid, SHP is one of the most viable options because it avoids the high costs of infrastructure for energy´s transmission and the increased final cost of the service. In addition, the SHP is one the cleanest options for future power production in Europe because large-scale projects have already been exploited or now it is not possible to assume their environmental risks.

The SHP has many advantages over large-scale projects because it is not necessary to build dams. In these large structures, the rapid silting up of the reservoir reduces considerably its lifetime and productivity. This way of power production requires a high amount of energy with large civil works; it also generates social and environmental adverse impacts as affectation of the ecosystem, the displacement of local communities and wildlife in the area. There is an excessive production of methane due to the decomposition of submerged organic matter in the dam (Paish 2002).

The basic principle of operation in this technology is transforming the potential energy of water into mechanical energy through a turbine. This is the reason why SHP is suitable only in places that must have sufficient slope and water flow for power production. Then a generator is responsible for converting mechanical into electrical energy. The magnitude of the works depends on the population in the community where it will be implemented. The SHP require for operation minor civil works that involve a low cost and therefore are viable for small communities. This study is focused in mountainous rural interconnected areas.

It is necessary to build an intake, sedimentation tank, forebay, a pressure pipe or penstock and a powerhouse where the turbine and generator will be located as it appears in Fig 1.

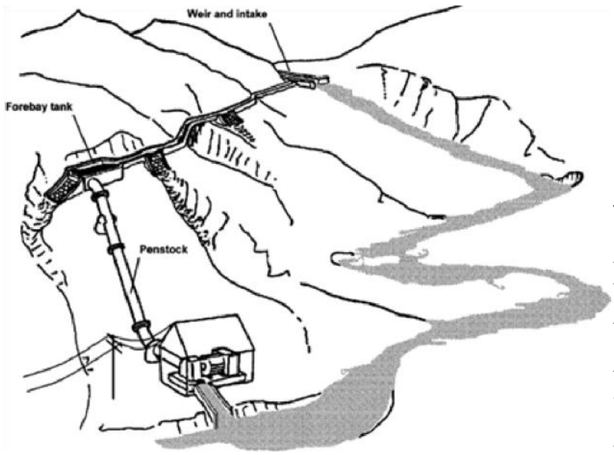


Fig 1. SHP scheme. Source: (Paish 2002).

SHP has many advantages and benefits with low environmental impact (Capik et al 2012; Nautiyal et al 2011; Sierra et al 2011; Dudhani et al 2006; Khan 2015; Zhang et al 2015; Barros and Tiago 2012), it is a technology that optimizes the land use with small area occupation and the buildings can be constructed with local materials to reduce the environmental impact. These plants can be located closer to consumer centers to reduce energy losses in transmission. In this way it is possible to decrease costs for consumers and improve living conditions because it needs higher level tasks in regions with low index of human development. If the system is handled properly, the only problem is erosion at the end of the process. It is easy to solve (Sierra et al 2011). It is necessary to continue the research in efficiency and adaptability of these kinds of systems to different geographical and hydrological conditions. Solutions that can guarantee a steady supply of energy throughout the whole year must be created, as proposal in this study.

According to (Okot 2013) there are three types of hydropower plants:

Impoundment: Is a large hydropower system which uses a dam to store river water. Then the stored water is used for the power production.

Diversion: In this case a portion of river water is directed towards a channel or penstock. In this system is not necessary to build the dam.

Run-of-river: This system uses water within the natural flow and it does not require impoundment or only a minimum.

Most SHP facilities are ‘run-of-river,’ so natural flow of the river is preserved. There is no need to build the reservoir to generate power. It is much smarter preserve natural flow of the river to avoid the problems associated with hydroelectric dams, such as flooding arable land, disrupting river temperature and composition levels. SHP plants can prevent these negative riverine effects of large-scale hydropower (Kosnik 2010).

The purpose of this paper is to review the potential of applying a Hybrid (SHP-Solar) power production system in mountainous rural areas in Colombia. It is also important to analyze in detail the law that allows the implementation of this technology. In order to carry out this analysis, a Hybrid station model will be designed. This solution looks for a system that guarantees a stable supply of energy throughout the year. This system with has as main source the hydroelectric power. It is complemented with solar panels that can supply energy in dry seasons. It will include meteorological, financial, technical and social factors.

This kind of investigation boosts the expansion of knowledge in this specific topic and gives the reader a realistic idea of what is an SHP system. This new scheme of technology is analyzed in its context and also opens a discussion about the possibilities for the implementation in the Colombian legal framework. The innovation in this case study is the complementary solar system proposed to maintain the energy production throughout the whole year.

According to the Law 1715 of 2014, which regulates the integration of renewable energies to the National Energy System in Colombia, it is possible to produce energy to eliminate the cost of the energy bill. It also allows to natural or legal persons to act as small energy producers. One of the main objectives of this law is to diversify the energy matrix. This diversification is important to maintain the energy flow when a specific source fails.

2 SHP in Colombia. There is no internationally agreed definition for SHP and its classification is based only on a country's level of hydropower development.

Table 1. SHP international definitions.
Source: (Jiadong 2005).

Country/organization	Micro (kw)	Mini (kw)	Small (kw)
Brazil	< 100	101–1000	1001–30,000
China	≤ 100	≤ 2000	≤ 50,000
Philippines	–	51–500	< 15,000
Sweden	–	–	101–15,000
USA	< 500	501–2000	< 15,000
India	< 100	< 2000	–
Japan	–	–	< 10,000
Nigeria	≤ 500	501–2000	–
France	< 500	501– 2000	< 50,000
New Zealand	–	< 10,000	< 50,000
United Kingdom	< 1000	–	–
Canada	–	< 1000	1001–1500
Russia	–	–	< 30,000
Norway	< 100	101–1000	1000–10,000
Germany	< 500	501–2000	< 12,000
Turkey	< 100	101–2000	< 10,000

In Colombia, the UPME (Unidad de Planeación Minero Energética) is the government's agency responsible for administering energetic and mining resources. The small hydropower plants are defined as developments below or equals to 10 MW.

Table 2. SHP Definitions in Colombia.
Source: Adapted form (Sierra et al 2011).

Type	Power (MW)
Micro Central	<0.1
Mini Central	0.1 to 1
SHP	1 to 10

A SHP production is defined as the energy obtained from that unconventional source of renewable energy that is based on the small-scale water bodies.

Table 3. SHP definitions according to the head.
Source: Adapted form (Penche 2004).

Type	Head
Low	2 – 30 m
Medium	30 – 100 m
High	100 m and above

There is also another classification, it depends on the type of the SHP scheme; it could be an **ISOLATED** or an **INTERCONNECTED** system.

Considering that this country has large mountainous regions is it possible to take advantage of water falls in the sub-urban and rural regions that have great potential of energy production because there are huge amount of water currents. In addition, it counts with slope on the ground, which is another requirement for a good performance in terms of energy production.

Methodology. An investigation is based on the process of collecting, interpreting and analyzing observations (Yin 1994). It establishes a logical model with evidence that allows the researcher to elaborate hypothesis regarding the causal relationships between the variables to be studied. It is possible to make generalizations when the interpretations can be extended to different situations or populations. The main components of the research are listed here:

1. Study questions: Can the population benefit from the results produced in the study?. Which will be the populations that will be benefited from this study results?. It would be possible with the new regulations in energy production to eliminate the increasing cost of energy bill?.
2. Study Proposition: A functional, technical and economic feasibility study is proposed. The prices and values evaluated correspond to **year 2019.**
3. Study unit: An average household in the defined region (Mountainous sub-urban or rural areas in Colombia).
4. Logic that unites the data and propositions: The collected data refers to **average energy consumption** and its associated costs. The main idea of this research is to determine if it is more expensive to pay the energy bill or install the proposed SHP Scheme to produce the power required in a 10 years Period.
5. Criteria for interpreting the findings: Economic engineering concepts for medium-term planning.

An empirical theme can be represented by a case study, in this way of investigation with the establishment of a set of procedures. It is really useful to define the decision making in any situation. The case study analyzes the reasons for each decision, how they were implemented and determine the relevance of the results.

In this work, a case study research is developed. It is a research about a contemporary phenomenon within its real-life context. This study analyses the average energy consumption in a household located in rural areas of Colombia and how to guarantee a steady power supply from two renewable energy sources. It is possible using the hydro and sun power. This is an efficient solution because the power production occurs in the same place where it will be consumed, decreasing costs and losses.

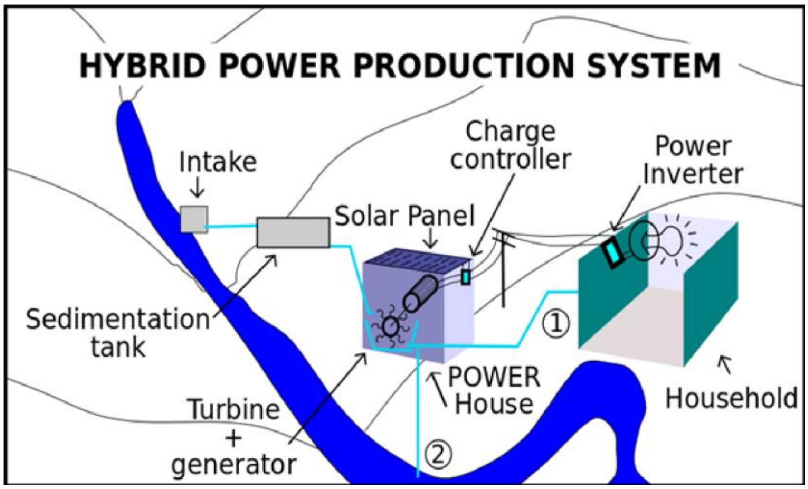
This is an illustrative case study. It establishes a descriptive evaluation and intends to clarify specific topics (according to Colombian context and laws). For science, this type of investigations is useful for making familiar the unknown concepts. It also provides to readers a common language about this new knowledge in that specific subject. It is also an evaluation study because it analyzes the feasibility of implementing a SHP in its real context.

HYBRID POWER PRODUCTION SYSTEM. (SHP-Solar). This study proposes the design, calculation and viability study for a hybrid power generation station located in the mountainous regions of Colombia. The objective is to analyze the following project: **To install a hybrid SHP-Solar power production system to supply energy for a housing unit located in Colombia.** According to the UPME report, a **Colombian average household** of four inhabitants consumes **166.33 Kw*h/Month**. The goal is to meet the energy demand to avoid the payment of the bill when there is an interconnected system. In this case, the national network can be used as a battery, serving as an energy source when there is no energy production and also functioning as storage when the system is producing.

This Hybrid system has as main source of power production a 500w SHP and is complemented with a 300w solar system that uses the same facilities and connections. This solar panel will provide energy in the dry season mainly.

According to (Ávila et al 2014), the increase in the frequency of extreme hydro-meteorological events affects rivers flow. Extreme events associated with ENSO (El Niño Oscilación del Sur), may decrease the generation on the SHP and at this time, photo-voltaic system will provide energy for consumption. It is a complementary system that handles the same voltage (12 volts) to complement the proposed SHP scheme.

Fig 2. Hybrid SHP-Solar Power Production System - Proposal.

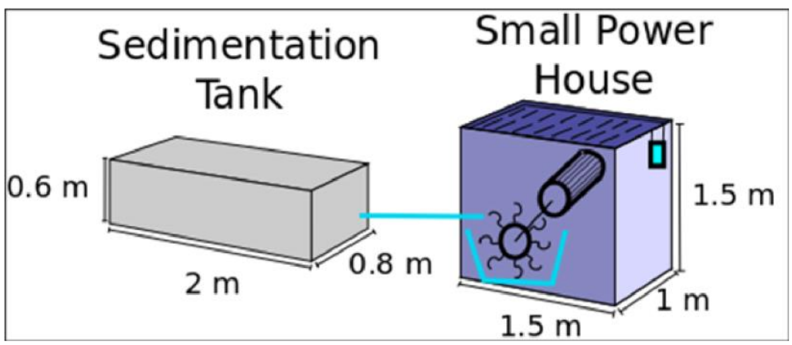


This Hybrid Scheme in **Fig. 2** will produce the energy needed in an average household (average consumption of four people) in Colombia. According to legislation, it is possible to eliminate the payment of the energy bill. There is some Kwh left over per month to trade in the energy market. This Extra energy production will not be included in the economic study because the rules for its commerce in the energy market are not clearly defined in the law. The study will focus on cost that will avoid the proposed Hybrid production system for interconnected zones.

The energy production process does not contaminate the water, so it is possible to use the water to supply the house (Use 1 of water) or it can be delivered back to the water stream (Use 2 of water) as seen in **Fig 2.**

For SHP implementation, it is necessary to build the structure to catch the water (Intake) and a sedimentation tank to protect the equipment and to control the flow. Then is required to install a pipeline to carry the water and construct a small power house to install the turbine and the permanent magnet alternator. The construction and installation of these facilities is included in mounting and installation item. It will need a bearing shaft and pulleys to transmit the movement and optimize the efficiency of the system. Also is necessary to install the charge controller to regulate the signal and the power Inverter for the use of energy at the proper voltage. Finally an electrician makes the connections and the installation of the bi-directional energy meter to be able to measure the power production and consumption. The difference between these two values indicates how much surplus was generated by the housing unit. Engineering cost refers to project management.

Fig 3. Design dimensions for Small Power house and Sedimentation tank.



This illustrative scheme in **Fig 3.** Shows the dimensions of the structures to build during the assembly of the Hybrid power production system. First start with the construction of the intake. It will depend on the water source and terrain topography. Then comes the installation of the pipes that will lead the water to the sedimentation tank. Here, the dimensions were chosen to reduce the speed of water flow and to allow the greatest amount of suspended particles for settle at the bottom. That is why the tank is longer than wide. There must be a considerable height difference between the tank and the power house to maximize energy production. This should be taken into account in each installation because conditions may vary markedly. Then, the water arrives to the Small Power

House and the energetic transformation takes place in the turbine-generator group. The dimension of the power house makes possible the installation of the devices and provides space for periodic inspection. The power house should be as small as possible to reduce installation costs. The solar panels, located at the roof and the generator are connected in parallel to the charge controller and through the wires the energy is taken to the inverter. Finally, the inverter delivers the energy at a voltage suitable for the operation of domestic appliances (120 V). It is able to return part of the energy to the national grid when interconnected.

Finding this type of equipment is becoming easier in the local market but in the international market (Internet) it is possible to get a vast variety of brands and products. Due to this diversity of products, currently is cheaper and easier to acquire merchandise to develop innovation projects.

There are a large number of manufacturers for the most diverse specifications. In this case, the total cost of the project is reduced to the purchase of the equipment, execution of a small civil work for installation and the function of an engineer administering the whole project (All costs included).

VIABILITY STUDY. Colombia is classified as one of the countries with greater water supply in the world. In a study of the Water resources information system IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales) (Franco 2010), a water yield of 63 l/s-km2 is exceeding six times the global yield that is estimated in (10 l/s-km2). It is also three times higher than the performance of Latin America (21 l/s-km2).

According to the UPME report (Atlas hidroenergético de Colombia) (Obregón 2015) this country presents optimal conditions for power production due to its pluviometric regime and orography. Currently about 80% of energy production comes from hydroelectric power plants. The hydro energetic potential was calculated as follows:

$$Pot = \tilde{a} * Q * \ddot{A} \quad * \grave{i} \quad (1)$$

Equation (1). Hydro potential calculation.

For this calculation, Pot is power generated, γ is the specific weight of wa - ter, Q is the flow, ΔH is the hydraulic fall and μ is the system efficiency. After the superposition of the hydrological and topographical maps, they obtained the following table 4 with the Hydro potential accumulated by central type and place identified for power generation.

Table 4. Colombian Hydro potential by region.

Source: Adapted from UPME report (Obregon 2015).

Hydrographic Area	Central Type [Kw]			
	Pico	Micro	Mini	Small
Amazonas	285	2799	26948	903311
Caribe	210	1935	16843	436476
Magdalena-Cauca	514	5229	47567	1646204
Orinoco	360	3599	35789	1230958
Pacífico	165	1647	15984	568657
Total	1533	15209	143132	4785606

According to this table, all Colombian regions have potential for hydroelectric energy production but especially the Magdalena-Cauca Region has higher possibilities due to the results of this national report.

$$500W * 24\frac{h}{day} * 30\frac{days}{Month} * E = 324\frac{Kwh}{Month} \qquad (2)$$

Equation (2). SHP Power Production calculation (With Efficiency E=0.9).

SOLAR ENERGY CALCULATION. For this calculation, first is important to define some characteristics of the equipment to be used. The chosen modules are 3 units of 100W and 12V solar panels with the following specifications:

Table 5. Solar Modules specifications.

Open circuit voltage	I_{max}	21.6
Short Circuit Current	V_{max}	5.56
Sun peak hours	SPH	4
Performance	P	0.9

To estimate the energy produced by each module it is necessary to calculate:

$$E_{Pa} = I_m \cdot V_m \cdot SP \cdot F \quad (3)$$

Equation (3). Solar energy Production.

This equation gives a useful estimation of solar power production. Each panel produces 432.35 w*h/day, so the 3 units are going to generate 1297 w*h/day or **38.91 KW*h/Month.**

For the energy production, it is necessary to install the equipment and develop the civil works that follows:

Table 6. Requirements for SHP implementation.

EQUIPMENT	Quantity	Cost $USD	Provider	Cost $ COPs
SkyMAX DC permanent magnet alternator 12v, 500w	1	247	SkyMAX	$ 853,138
Aluminum Pelton Water Wheel for Micro Hydro Generator / Turbine + Adapter Arbor	1	54	GreenergyStar	$ 186,516
Bearing shaft	1	14	NB	$ 48,356
Machinery Pulley O Type 29.5" Inner Girth Rubber Drive V Belt	2	12	Uxcell	$ 41,448
Xantrex C40 Charge Controller for Wind Turbines Hydro Solar Panel	1	171	Xantrex	$ 590,634
Grid tie inverter DC to AC 110v 220V Pure Sine Wave 1200 W home system	1	216	Y&H	$ 746,064
Sunner power 100W 12V Mono Crystalline Solar Panel	3	330	Suner Power	$ 1,139,820
Connection project	1	60	Local Labor	$ 207,240
Mounting and Installation	1	456	Local Labor	$ 1,575,024
Bi-directional Energy Meter	1	165	Nansen	$ 569,910
Direct Cost		1725		$ 5,958,150
Engineering (30% of Direct Cost)	1	517.5	Local Labor	$ 1,787,445
TOTAL		2242.5		$ 7,745,595

It is necessary to do an economic study to determine if worth's developing this project in the medium term. According to the literature, SHP is systems that can last 50 years with minimal maintenance (Paish 2002). Due to the uncertainty of any enterprise is established **10 years as useful life of the project.** The following cash flow is a representative model of the investment alternative under study. For the purpose of this study, the income produced by the extra energy generated will be discarded. The Colombian government has not yet regulated the sales dynamics for this consumer good in the energy market. Follows the economic analysis of the project under study:

Table 7. Cash flow of proposed project.

Cash Flow				
Period (Years)	SHP Project Investment (USD)	MARR=8%	Current (2019 USD)	Current (USD) Accumulated
0	-2242.5	1		
1	288.76	0.93	267.37	267.37
2	300.77	0.86	257.86	525.23
3	313.28	0.79	248.69	773.93
4	326.32	0.74	239.85	1013.78
5	339.89	0.68	231.32	1245.10
6	354.03	0.63	223.10	1468.20
7	368.76	0.58	215.17	1683.36
8	384.10	0.54	207.52	1890.88
9	400.08	0.50	200.14	2091.02
10	416.72	0.46	193.02	2284.04

On the initial period (years), the investment is done (negative value). Then, the following periods the investor will stop paying the value of the energy bill, which are positive values in the cash flow. The cost of maintenance will be deducted from the savings in the payment of energy (10 USD/Year). A Minimum Attractive Rate of Return (MARR) is the interest rate equivalent to the higher profitability of current and low risk applications. It was assumed by analyzing the **Colombian economy and its opportunities.**

RESULTS AND DISCUSSION. Colombia has 1533 Kw of power potential for pico centrals and this demonstrates its functional viability for the proposed system. According to the UPME report (Obregón 2015) it is possible to install at least 3066 plants of 500w throughout the country. The proposed system in this study can be used in mountainous Colombian regions with water currents for power production.

The functional and technical viability is defined in the references that demonstrate the effectiveness of the proposed SHP generation system in different countries (Paish 2002;Capik et al 2012; Nautiyal et al 2011; Sierra et al 2011; Dudhani et al 2006; Khan 2015; Zhang et al 2015;

Barros and Tiago 2012; Okot 2013; Kosnik 2010; Jiandong 2005).

There are currently many manufacturers all around the world for the different equipment needed to install a Hybrid SHP- **Solar** scheme. There are also companies providing renewable energy services that guarantee the start-up and operation, offering technical viability for SHP implementation.

This technology represents an excellent source of clean energy for the interconnected and isolated areas. Also it is really useful for the most vulnerable communities in the more distant places. It is particularly suitable where the power supply by connecting to the national grid would be economically impossible. It could be the perfect way for communities to obtain energy independence, which it is clean, reliable and sustainable. Thus, the people benefited with this type of technology are those who have the access to the water supply in any socio-economic condition.

The big challenge is to optimize and expand this technology to thousands of communities so that they can get access to electricity. Is worth mentioning that because of hydrology and geography of Colombia it is possible to expand the electric coverage and improve the living conditions of many people.

The economic engineering provides the decision criteria, for the choice between do the investment or pay the bill for the next 10 years.

On the first case, there is an investment of **2243 USD**. The net present value **(NPV)** is the current value of an investment done in several periods. If positive, it means that including discount rate, the project presents a **41.54 USD** profit. With this result, it is clear that it is cheaper to install the proposed system than paying the bill for 10 years. The difference is minimal **(41.54 USD)** but it is necessary to keep in mind that the system will continue working for several years, depending on the maintenance.

Table 8. Decision criteria factors.

Hybrid SHP-Solar Project	
MARR	8.0%
NPV	$41.54
PMT	$6.19
CBI	1.02
IRR	8.38%
DPB (Years)	9.78

The regular payment **(PMT)** is a periodic payment due to the investment. It represents that the investor will get **6.19 USD** per year. The cost-benefit index **(CBI)** indicates that for each dollar invested, it will return **1.02 USD.** It is important to note that after 10 years the investor will have recovered the money invested (with **NPV** as profit) and will not have to pay the electric power service because of the implementation of the hybrid system. According to the literature, a SHP can last 50 years with minimal maintenance. In this way, there would be another 40 years to take advantage of the operation of the system.

The Internal return rate **(IRR)** is an important criteria. If it is greater than the minimum attractive rate of return **(MARR)** means that the project is more profitable that doing a low risk investment. Given that the IRR is only 4.75% greater than the MARR, it represents that implementing the proposed system has similar risk of investing in a safe way. Values close to the MARR imply greater risk. The discounted pay back **(DPB)** is the time in which the investment will return, in this case are 9.78 years for the Hybrid SHP-Solar scheme proposed.

It is necessary to make a projection for the cost of the energy bill on the next ten years to compare with the obtained values on the economic analysis. According to the DANE (Departamento Administrativo Nacional de Estadística) and **Banco de la República report**, the average inflation is

4.16% on the last ten years. To estimate the cost of the future bill was calculated the cost of energy for an average consumer unit (166.33 KW*h/Month) with a tariff of $ 517 COP/Kwh (average cost in Colombia). It was projected with a constant inflation increase. Therefore, in the next 10 years this household would pay about **3614 USD**. Comparing this value with the investment for the hybrid system, it is determined that economically it is more efficient to install the proposed generation system (with initial investment of **2243 USD**) that paying the bill in the useful life of the project.

The ENSO (El Niño Oscillations del Sur) events produce affectation on rivers flow so the efficiency of the power production process decreases. Owing to this reduction of the water resource, It was assumed a total efficiency of the system in 60%, producing **216 KW*h**/Month. It fulfills the average consume of the household. The proposed solar system is a backup in case the river flow decreases to levels inferiors for energy production. These climatic events are occurring with more frequency and severity. That is why it was determined to include a solar energy generation system, since solar radiation can be used throughout the year if necessary. It was previously calculated that this solar power will contribute with **38.91 KW*h/Month.** The complete system will produce 254 KW*h/Month in the most adverse conditions (historical decrease in rivers flow). This value exceeds the energy demand of an average household in 88 KW*h/Month. In this way, the proposed Hybrid system can guarantee a stable and constant supply of energy throughout the year. This is possible when the intake is constructed for operation of SHP with low water levels.

According to the Law 1715 of 2014, it is possible to sell the extra energy produced. This provides the general conditions so that natural or legal persons can become small power production centers. The normative resolution 024 of 2015 regulates the auto-generation in large scale. It also regulates the small scale (Schemes Under 1MW) until its own regulation takes effect. The CREG (Comisión de Regulación de Energía y Gas) is responsible for defining energy policies adopted by the Colombian Ministry of Mines and Energy.

Conclusion. The implementation of the hybrid system in mountainous areas in Colombia is viable. The functional requirements are guaranteed, this area counts with a vast quantity of water currents and the geographical formations give the necessary ground inclination for power production. In the local and international market (Internet), it is possible to get all the necessary devices for the Hybrid SHP-Solar system implementation. A contractor engineer can execute the civil works required. There are companies dedicated to support this kind of innovation projects. The viability study reveals that it can be seen as a source of profit because the energy cost is increasing constantly. Thus is possible to guarantee its economic viability. Besides the law 1715 of 2014 established the legal framework to boost the development of renewable energy sources. It should to be noted that this study reveals that Colombia presents all the necessary conditions to increase the implementation of renewable energy projects. In this case study is shown that this kind of projects is legal, functional, technical and economically viable.

To answer the study questions asked in the methodology, the entire Colombian population can be benefited from the result of this research. If they are connected to the national grid they can install a Hybrid SHP-Solar system to eliminate the energy bill and produce an economic income. With the new regulations, consumers can become producers. Thus, it is possible to get energy autonomy and produce extra energy to sell to distribution companies. It will depend on the power of the system and the efficient use of energy.

The proposed technology emphasizes the efficient use of energy because it is smarter to analyze the consumption of the appliances that currently make up a home. Most electrical appliances use transformers that convert 110v power to 12v or 5v power. Cell phones, light bulbs, modern sound equipment, computers and even televisions can be found in the market working at low voltages. In this way, unnecessary transformations and losses can be avoided. If the energy is produced in 12v, as proposed in this study, it is efficient to use this tension directly because they will not require transformations. The conversion will only be carried out for devices that need greater voltage and power, using the power generates in an intelligent and efficient way.

Constructing the proposed system, the consumer becomes a producer and transforms the paradigm of relationship with companies that provide services. In this case, with a **2243 USD** investment, an entrepreneur can eliminate the energy bill payment for at least 10 years (useful life of project). According to the forecast made on the viability study, the cost of energy for an average Colombian household in 10 years can reach **3614 USD** including inflation on current currency (2019). After this period, it will only need to replace some equipment, extending the useful life of the project as it takes advantage of previously installed connections. For these reasons and projecting the future scenario, it is an interesting investment option in economic terms.

It is possible to decrease the value of the initial investment when it comes to the installation of a power production system for a new house. For the house construction, the designer can take into account the use of the water that comes out of the power generation system and take advantage of it for the housing water supply. Thus it is possible to use the water that comes with a previous treatment. Since it has double use, its cost decreases.

Using renewable energy sources is a path to decentralization of power production. This is a goal of the energy market and the government. In economic terms, expanding the sources of energy production means that investments for large electrification projects can be postponed, that is, it increases the term for investments in this regard. It is better to produce the energy locally avoiding the high transmission costs and the loss rate. A distributed power generation system leads to decarbonizing the global energy infrastructure (Scheer 2006). In this way, the energy actors will have multiple and simultaneous roles because they will become consumers and also power producers. To achieve this goal it is necessary to create intelligent and decentralized infrastructure solutions that boots people to be part of this new integrated energy system. This concept drives to an empowerment process of people and small rural communities assuming their ENERGY AUTONOMY.

To eliminate the high environmental and social risks of burning fossil fuels it is important to make the transition to renewable sources of clean energy, looking for distributed and decentralized power production. Throughout the planet it has been proven technologically, commercially and politically (Scheer 2006). Although there are interests that try to hide the benefits of the production of renewable energies, in practice it has been demonstrated that are reliable and sustainable systems. It is impossible to hide their potential. The energy Autonomy is aimed for sustainability in the local level. It allows creating a distributed power production model. It must be adjusted to the needs of people with a respectful vision of environment.

The law 1715 establishes the general regulations for the renewable energy production and its efficient management. It is created an incentive system for the providers of electricity service in non-interconnected areas, to partially or totally replace their generation with diesel by FNCE (Non-Conventional Energy Sources). It also creates FENOGE (Fund for Unconventional Energies and Efficient Management of the Energy) to finance FNCE programs and efficient energy management, as indicated in Article 10 of Chapter II in the Law.

Incentives.

- Those who are obliged to declare rent and directly invest in this meaning, they will be entitled to reduce their declaration by fifty percent annually (50%) of the total value of the investment made.

This applies for the 5 years following the year taxable in which they have made the investment.

- Exclusion of the Iva (consumption tax) for equipment, elements and ma chinery national or imported services that are intended for pre-investment and investment in the production and use of energy from non-conventional sources.
- Accelerated depreciation will be applicable to machinery, equipment and civil works necessary for the pre-investment, investment and operation of the generation with FNCE (Non-Conventional Energy Sources) that are acquired and/or constructed, exclusively for that purpose, from the validity of this law. For such purposes, the annual rate of depreciation will be less than twenty percent (20%) as the annual global rate.

However, it does not have the technical requirements to select the necessary technologies to link small producers with the SIN (National Interconnected Energy System) (Escobar and Quitian 2015). There is great importance and need for the efficient application of this Law throughout the country and especially in the Non-Interconnected Areas. To fulfill basic needs it is essential to reduce the gaps in the provision of energy especially in countries with lower development index. Thus, it will be possible to balance the standard of living of people, creaThe results of this study are only for interconnected areas. In this case the national network serves to avoid the use of batteries. It is possible to apply this proposed System in isolated areas too. It would only be necessary to complement the system with a bank of batteries that can store and regulate the power produced. Commercially available batteries have high cost and short service life (5 years on average). This would increase considerably the cost of installing the proposed system. It would be necessary to analyze each case because in places far from the national network it can be cheaper than bringing energy from faraway places.

Colombia presents favorable geographical conditions for the generation of ERNC (Non-conventional Renewable energies), which facilitates and encourages investment in projects of this kind. In addition, there are tax incentives that benefit considerably and reduce the tax burden to those investors or companies that assume the generation of ERNC. Finally, it is worth highlighting the current environmental and economic context in which the country's economy is directly affected by the fall in oil prices. This fossil fuels presented production and reserve decreases since it is an exhaustible and non-renewable resource. In this way, other sources of power production are needed to be economically and environmentally sustainable.

Due to the decentralization of energy production, the following impacts are observed in the energy market:

- Diversification of energy sources.
- Expansion of renewable sources technologies.
- Creation of a new concept: Energy autonomy.

Currently, different sources of energy are needed to guarantee a steady supply throughout the year. Expanding the renewable energy sources is an excellent way to sustainability. Also it is important to highlight that the access to this technology will result in an empowerment process leading to create better living conditions, improve general knowledge about energy and originate high level jobs in rural communities. Some advantages of SHP implementation:

- Low Operation costs and simple maintenance.
- This kind of Systems has a long useful life (50 years).
- Easy application technology.
- Intelligent water use system to improve investment scheme.
- Reduces transmission losses in the network.
- Avoid dependence on fossil fuels.

- Minimal environmental impact.
- Reduction of greenhouse gas emissions.
- Empowerment process of people.
- Creation of opportunities for the Colombian industry and entrepreneurs.

Some challenges to overcome for SHP installation:

o Economic: Initial investment.

o Lack of consumer information and opportunities in the new energy market.

o Creation of new policies that encourage the implementation of this kind of enterprises.

o Application conditioned to the availability of water resources.

A limiting factor is the lack of information about SHP and Solar energy in addition to the discouragement in past decades by previous governments. Currently exists a legal framework for implementation of renewable energy projects but that information is not widely known. An objective of this work is to publicize the benefits offered by the legislation on those interested in installing renewable energy generation systems.

According to the Colombian definition, the proposed system is a SHP micro central. For future works, it is recommended to develop economic studies on mini-generation and small-generation systems that are likely to have higher performance in energy production and profitability. Also, it is necessary to create new policies where people can have access to this type of technology with technical support from the government. These Power production systems are keys to generate social welfare.

References.

Ávila D. et al (2014). Análisis de la influencia del niño y la niña en la oferta hídrica mensual de la cuenca del río Cali. Revista Tecnura, Vol. 18, No. 41, pp 120-133.

Banco de la República, Colombia (2018). Índice de precios al consumidor (IPC), http://www.banrep.gov.co/es/ipc. Accessed April 12 2019.

Barros RM, Tiago Filho GL (2012). Small hydropower and carbon credits revenue for an SHP project in national isolated and interconnected systems in Brazil. Renewable Energy, 48, 27–34.

Capik M. et al (2012). Hydropower for sustainable energy development in Turkey: the small hydropower case of the Eastern Black Sea Region. Renewable Sustainable Energy Rev, 16, 6160–72.

Dudhani et al (2006). Assessment of small hydropower potential using remote sensing data for sustainable development in India. Energy Policy, 34, 3195–3205.

Escobar W, Quitian D (2015). Impactos de la reglamentación de la ley 1715 de energías renovables no convencionales en Colombia. Econografos 84.

Franco, O. et al. (2010) Estudio Nacional de Agua. Agua superficial, Caracterización de la oferta. IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales). http://documentacion.ideam.gov.co/openbiblio/bvirtual/021888/Preliminares.pdf. Accessed 10 April 2019.

Houghton J.T. et al. (2001). Climate change 2001: the scientific basis. Cambridge, UK. Cambridge University Press. ISBN 0521807670.

Jiandong (2005) Small hydro power – China's practice. China Water Power Press.

Khan R (2015). Small hydro power in India: is it a sustainable business? Applied Energy, 152, 207–216.

Kosnik L. (2010) the potential for small scale hydropower development in the US. Energy Policy, 38(10), 5512–5519.

Nautiyal H.et al (2011). Small hydropower for sustainable energy development in India. Renewable Sustainable Energy Rev, 15(4) ,2021-2027.

Obregón N. et al (2015), ATLAS Potencial hidroenergético de Colombia. UMPE (Unidad de Planeación minero energética). http://www1.upme.gov.co/Paginas/Primer-Atlas-hidroenergetico-revela-gran-potencial-en-Colombia.aspx. Accessed 12 April 2019.

Okot DK (2013). Review of small hydropower technology. Renewable Sustainable Energy Rev, 26, 515–520.

Paish, O. (2002). Small Hydro power: Technology and current status. Renewable sustainable energy Rev, Vol 6, pp 537-556.

Penche C (2004). Guide on How to Develop a Small hydropower Plant. Thematic Network on Small hydropower (TNSHP).http://canyonhydro.com/images/Part_1_ESHA_Guide_on_how_to_develop_a_small_hydropower_plant.pdf Accessed 12 April 2019.

Sandford, T., et al. (2014) The climate policy narrative for a dangerously warming world. Nature Climate Change, http://dx.doi.org/10.1038/nclimate2148.

Scheer H. (2006) Energy Autonomy: The Economic, Social & Technological Case for Renewable Energy. Routledge.

Sierra, F. et al. (2011). Pequeñas y microcentrales hidroeléctricas: alternativa real de generación hidroeléctrica. Universidad Nacional de Colombia, Informador Técnico. Ed 75, 73-85.

Yin R. (1994) Case Study Research: Design and Methods. Porto Alegre, BR. Sage Publications.

Zhang J. et al (2015). Carbon dioxide emission accounting for small hydropower plants – a case study in southwest China. Renewable Sustainable Energy Rev, 47, 755–761.

FUNDACIÓN GUARDAGUAS DE CARTAGENA (FAGUCAR)
y/o CARTAGENA BAYKEEPER (CBK)
Miembro de la Organización Waterkeeper Alliance de Estados Unidos.
Cartagena de Indias – Colombia.
2019

MAKARA 2019

CONGRESO INTERNACIONAL cambio climático EN COSTAS Y MONTAÑAS DE AMÉRICA