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Developing Sustainable Infrastructure for Small Hydro Power Plants through Clean Development Mechanisms in Colombia

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Abstract

Developing sustainable infrastructure projects in Colombia requires special instruments leading to implementing Clean Development Mechanisms (CDM). For this reason, different financing alternatives to traditional methods for developing Small hydropower (SHP) projects should be evaluated. This analysis shows the country's potential for developing SHP projects thanks to the numerous mighty rivers that generate electrical power. Furthermore, CDM is a globally used method to finance SHP projects. Hence, this paper proposes that the Colombian domestic demand could be met through these projects. The large hydropower plants, besides complementing the domestic demand, can export the remnant power. Additionally, the SHPs development cycle, particularly their financial phase is also analyzed. The results of this study show that sustainable funding mechanisms encourage the development of infrastructure in Colombia. Also, CDM would increase the development of power generating projects and these can be used in other sectors such as water, waste management, and highways.

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1. Introduction

Power is an important factor for the economic development of countries and its demand increases day by day. All human activities are directly linked to the use of power; it fulfills our basic needs. The annual total greenhouse gas (GHG) emissions derived from the global energy supply sector continues to increase. Combustion of fossil fuels still dominates the global energy market that is striving to meet the ever-increasing demand for heat, electricity and transport fuels [1].

In order to fulfill the current human needs, 81.3% of the energy used on the planet is generated from the burning of fossil fuels, being petroleum, natural gas, and coal the main sources. It is known that this type of power generation has resulted in the emission of greenhouse gases (GHGs) and that the accumulation of pollutants in the atmosphere is one of the causes of the climate changes observed [2]. According to this framework, the Kyoto Protocol (KP) has encouraged CDM aiming at two precise objectives:

The first one is to help the countries listed in Annex I (developed countries with transition market economies that signed the Kyoto Protocol) fulfill their KP commitment. The second one seeks for guaranteeing the transfer of environmentally sound technologies to the developing countries through the establishment of CDM projects from the most advanced nations leading to create benefit and encourage sustainable development in the developing countries. When a company considers a CDM project as a source of revenue and business feasibility, the ultimate goals of this project are issuing and trading CERs [3].

Several authors have discussed the transition from the traditional power systems to the renewable power ones through CDM projects as well as their social, economic and environmental effects. They have proved total emission reductions as a result of implementing renewable power systems in remote zones [4], [5], [6], [7], [8]. Any SHP, depending on its implementation details, may be configured as a CDM, since it is an alternative for the generation of clean, renewable electrical energy [3]. Also, several authors argue that SHPs cause little or no environmental effect, and might be considered as sources of clean energy [9]. According to Purohit [10], small hydropower projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to the sustainable rural development, if developed correctly.

On the other hand, other researchers like [3], [11], [12], [13] have assessed small hydropower projects as eligible for GHG emission reduction. It has been shown that renewable power technologies such as SHP can contribute to global sustainability through GHG mitigation [6], [14]. Additionally, other studies conducted in developing countries have shown that investments in more efficient technologies, the sound use of energy and the substitution of fossil fuels by renewable ones actually reduce the emissions of greenhouse gases.

Since SHP projects represent a significant source of renewable energy, which reduces GHG emissions, it is conceivable to find an opportunity for development in the CDM market; this increases the interest of investors [15]. Colombia and particularly, the Antioquia region present a substantial, high quality hydroelectric potential thanks to the combination of its natural waterfalls, mighty rivers and stable geological conditions [14]. Likewise, it presents an acceptable electrical connectivity that assists the transfer of power as well as road infrastructure. This fact grants access to the zones where these kinds of projects are established. These characteristics make Antioquia’s power plants suitable for developing sustainability and obtaining benefits from carbon credits without negatively affecting the environment. Given this scenario, SHPs constitute a major opportunity for sustainable development in this nation.

This paper is structured as follows. The next section provides a description of the CDM as a tool for increasing sustainable development, particularly for Non-Interconnected Zones. Section 3 describes Colombia's hydroelectric potential, and a case study on Antioquia region is analyzed. Finally, Section 4 provides the main remarks and opportunities for further research.

2. Clean Development Mechanism for Sustainable Development

The CDM is one of the three flexible mechanisms established by the Kyoto Protocol, which presents legally binding reduction targets for six greenhouse gases in industrialized countries. The CDM has been developed as a means to reduce greenhouse gas (GHG) emissions cost-efficiently by allowing emission reductions in developing and newly industrialized countries. These countries are credited and financed by the industrialized countries in the Kyoto Protocol. Each ton of CO_2 reduced in a Non-Annex I country becomes a ‘‘Certified Emission Reduction” (CER) and it is tradable in the carbon market. The CDM is thus, a financing tool to turn investment into clean energy technologies [16].

SHP projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development [10]. The CDM has certainly transformed renewable energy into the world's focus on sustainable development. The key feature of this mechanism is that the industrialized countries set their emission reduction targets and the developing countries can benefit from the implementation of clean energy technologies. Implementing CDM projects results in carbon emission reductions commonly known as CERs. Hydropower projects have emerged as one of the most popular projects to be developed into CDM project activities because of their environmentally benign nature. The sale of CERs could help to accelerate SHP development in Colombia.

The concept of sustainable development as used today dates back to the early 1980s. The definition formulated by the World Commission on Environment and Development (WCED) in their report, "*Our Common Future*" (also known as the ‘‘Brundtland report) still seems to be the most widely known and accepted one: "It is the development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations’’ [17].

2.1. Small Hydro Power for development in Non-Interconnected Zones (NIZ)

The general practice all over the world is to classify SHPs by their power output. Different countries follow different norms keeping the upper limit ranging from 5 to 50 MW. In Colombia, hydroelectric plants with power higher than 20 MW are called small hydropower plants (SHP). These types of power generating units constitute an attractive alternative for the electrical infrastructure in Colombia since they are exempted from paying a backup power fee. Additionally, they can freely share their power into the National Interconnected Electrical System (NIES) [18]. These two significant advantages are explained below.

Power backup is the electrical power generation capacity available to supply the demand in Colombia in the case of failure in other units; it is not necessary to supply that demand under normal conditions. The operating plants, which do not belong to the backup power system, must pay a fee to the government for each power unit produced.

The money received from this activity is transferred to the backup power system. SHP projects are not eligible for being part of the power backup system and consequently, they must pay that fee except if they have a capacity lower than 20 MW [19]. These projects also get additional benefits of sustainable development and are favored by some carbon credit dealers because it is easy to determine their baseline. It is also easy to comply with the requirements established by the United Nations Framework Convention on Climate Change in 2001 [20].

Furthermore, small hydropower plants are considered renewable energy sources with zero GHGs emissions [3], [13]. Besides, It has been found that SHP projects cause slight and localized impacts contrasted to the ones caused by the implementation of large hydroelectric centrals [9]. The negative environmental effects associated with the use of large hydropower plants have helped to focus on small-scale plants, which reduce these effects considerably [18]. SHP projects continue to be the most efficient, reliable, clean, and large carbon-free mechanisms and represent a flexible peak load technology way to generate electricity. These projects also produce minor amounts of greenhouse gases and a lifespan of up to 100 years, therefore, they constitute an attractive energy payback ratio even for developing countries [21].

SHP projects are considered a clean, renewable source of energy, emitting a very low level of greenhouse gases when compared to fossil fuels. It presents a low operating cost once installed, and can be highly automated. An additional benefit is that the power is generally available on demand since the flow of water can be controlled. One of the largest environmental benefits of SHPs is that there is not carbon dioxide produced during electricity generation. SHP projects do not require fossil fuels and do not emit greenhouse gases associated with the burning of fossil fuels. As such, it is one of the most environmentally friendly methods of electricity generation. Another environmental advantage of SHPs is that water is not polluted during the process and can be utilized for additional processes, such as crops or water supplies [22].

Small hydropower (SHP) projects are one of the most appropriate options to meet the increasing energy demand especially in countries like Colombia where a huge power potential is available in this sector. It is clean and renewable in nature, in contrast to fossil fuel-based generation, which pollutes the environment.

3. Colombia’s hydroelectric potential

Hydropower is the most widely used renewable energy form and represents a fifth of the world's electricity. It has contributed to the economic growth in many countries including Brazil, Canada, China, the US and Norway [8]. XM S.A. ESP is the company that currently manages the National Interconnected Electrical System (NIES) of Colombia and the Wholesale Energy Market (WEM). In its report *"NIES Operation and Market Management",* it reveals that the Net Effective Capacity (NEC) installed in the NIES at the end of 2014 was 15,489 MW.

In Colombia, the Energy Generation Expansion Plan from 2014 to 2028 aims at increasing the installed capacity by 15,489 MW, represented mainly by hydroelectric plants, thermal gas, and coal. From that amount, 10,315 MW will be attributed to hydropower plant projects [23]. There is vast hydrological potential thanks to the country’s privileged geographic location. This potential has been widely explored in large hydropower projects benefiting big cities and other significant consumption centers, excluding in many cases, non-interconnected rural zones. In some regions, there are various SHP projects at their exploratory phases, while other regions totally ignore the hydropower potential they have.

Table 1 records the Net Effective Capacity in December 2013 and 2014. When comparing 2014 and 2013 an increase of 930 MW can be observed (equivalent to 6.4%). This increase is mainly because new plants started their operations: Hidrosogamoso hydroelectric plants, 819 MW; Dario Valencia Samper, Units 1 and 5 (50 MW each); el Popal, 19.9 MW; Salto II, 35 MW and Laguneta 18 MW.

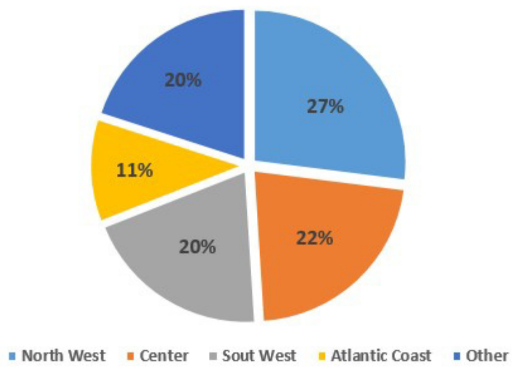
Table 1. NIES Net Effective Capacity between December 31, 2013 and 2014.

Source	2013 MW	2014 MW	Var. (%) 2013-2014
Hydroelectric	**9,315**	**10,315**	**10,7%**
Therm	**4,515**	**4,402**	**-2,5%**
Gas	1,972	1,757	-10,9%
Coal	997	1,003	0,6%
Fuel	307	297	-3.3%
ACPM	917	1,023	11,6%
Small plants	**662.2**	**694.7**	**4,9%**
Hydro	560.5	584.9	4,4%
Thermal	83,4	91,4	9.6%
Wind	**18.4**	**18.4**	**0,0%**
Cogeneration	**66.3**	**77.3**	**16,6%**

Source: [23]

The Colombian Government is currently working on the implementation of small hydropower projects in non-interconnected zones. Years ago, the Institute of Nuclear Sciences and Alternative Energies estimated the potential execution of small hydro projects in about 25,000 MW. Another study concluded that the electric power industry covered over 80% of Colombian rivers representing great potential of small hydropower plants. This potential was divided by areas as Figure 1 shows:

Figure 1: Potential for Small hydropower plants in Colombia



Source: the authors based on [23]

The trend is to increase the penetration of unconventional energy sources (including SHPs) mostly within the NIZ (Non-Interconnected Zones) passing from 8% in 2009 to 30% in 2020. In the NIES, the participation of unconventional energy will increase to 6.5% in 2020 according to the trend in reducing technology costs and the plans and studies of the major players in Colombia's energy sector. In summary, it is clear that the participation of SHPs will increase in both, the NIS and NIZ but there are not any specific goals regarding the installed capacity for this energy source. According to this, small hydropower systems have the highest impact on the installed capacity with 75.9% of the total participation. It expresses a specific interest of the Government to carry energy to NIZ.

3.1. Case Study: Antioquia's hydroelectric potential

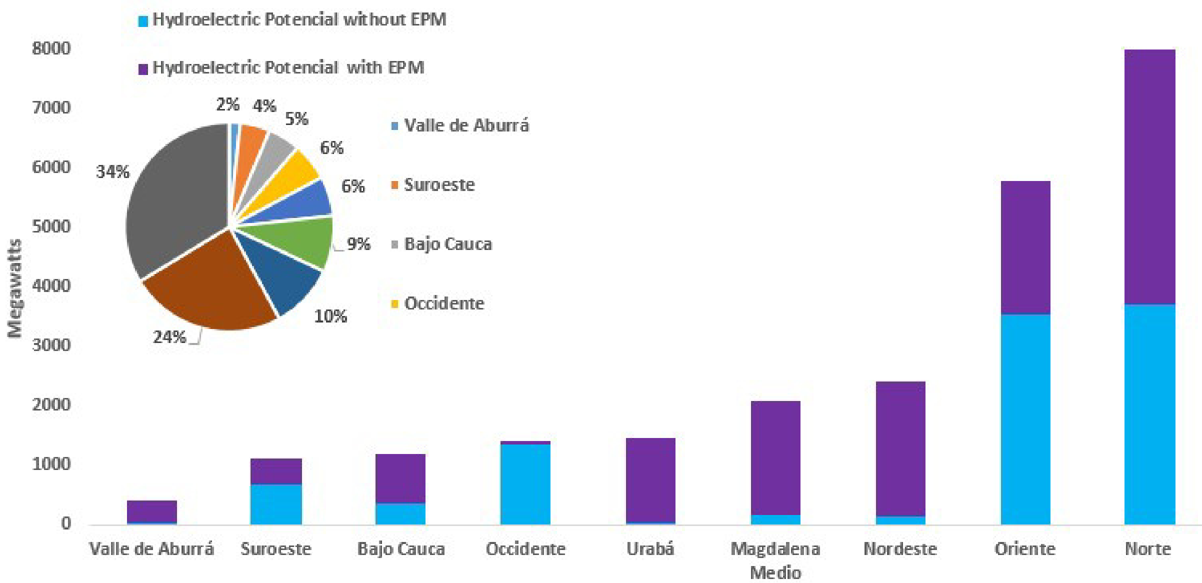
Antioquia has a generous, high-quality hydroelectric potential thanks to the successful combination of its rich water flows and natural regulations; numerous topographical waterfalls and stable geological conditions are also present. It offers adequate connectivity infrastructures of both road and electricity, which helps accessing the project areas and allows the transferring of the energy produced [14].

In 2010, Antioquia presented 45 operating hydroelectric plants. That means 3,803 megawatts, which corresponded to 28.6% of the country's total capacity (13,279 MW) (UPME). Six plants were built with a total potential of 3,503 MW. The remaining identified potential is found at different development phases: 6,784 MW were at the feasibility phase and 1,008 MW at the design phase [14].

Antioquia has one of the largest companies in the hydropower sector in South America: Empresas Públicas de Medellín (EPM). Antioquia's hydroelectric potential corresponds to a total of 23,947.26 megawatts. From that amount, 13, 878.7 MW correspond to EPM's hydroelectric projects and 10,068.56 to other entities' projects [14]. Figures 2 to 6 show the hydroelectric potential of Antioquia in 2010. This capacity appears classified by sub-regions, by the size of the plants and projects, and their phase of development.

According to 2010 data, Northern and Eastern Antioquia's sub-regions possess the highest hydroelectric potential. The Northern region offers 8,062.29 MW (34%) mainly composed of the Cauca, Porce, Grande and Guadalupe rivers basins. The Eastern one has 5,806.43 MW (24%) corresponding to Nare, Guatapé, San Carlos and Samaná Norte rivers basins [24].

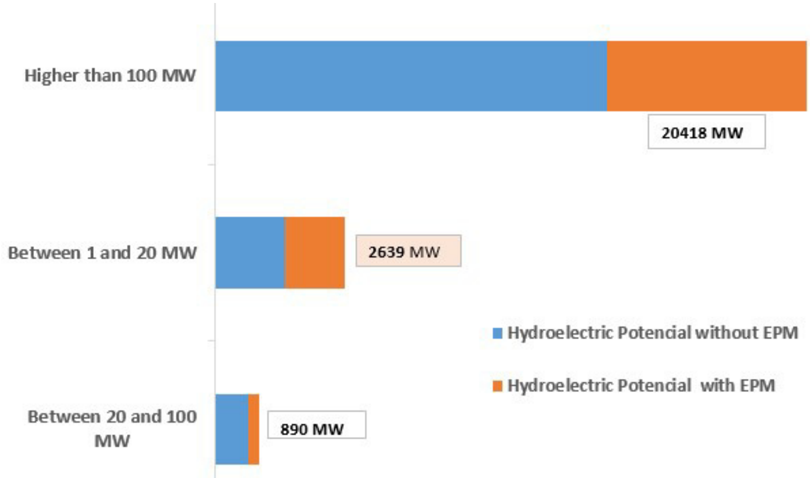
Figure 2. 2010 Antioquia's hydroelectric potential: sub-regions.



Source: the authors based on [14]

In 2010, within the range of lower than 100 MW ratio plants, there were 3,529.26 MW. That represented an increase in the potential of SHPs. It evidences an emphasis in the developing of this type of plants.

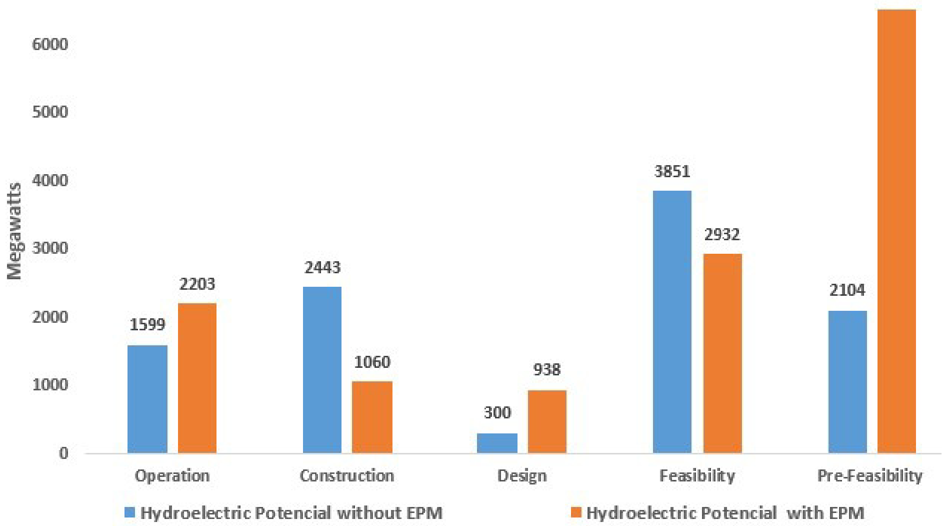
Figure 3. 2010 Antioquia's hydroelectric potential: power range.



Source: The authors based on [14]

As mentioned before, Antioquia had 45 operating centrals with a total power of 3,802.91 MW in 2010. 2,203.7 MW out of the previous amount corresponded to 24 EPM plants. Below, there is a comparison between Antioquia region's potential and the Latin American countries. As showed in the figure below, Antioquia held the ninth position over the Central American countries and three South American ones [25].

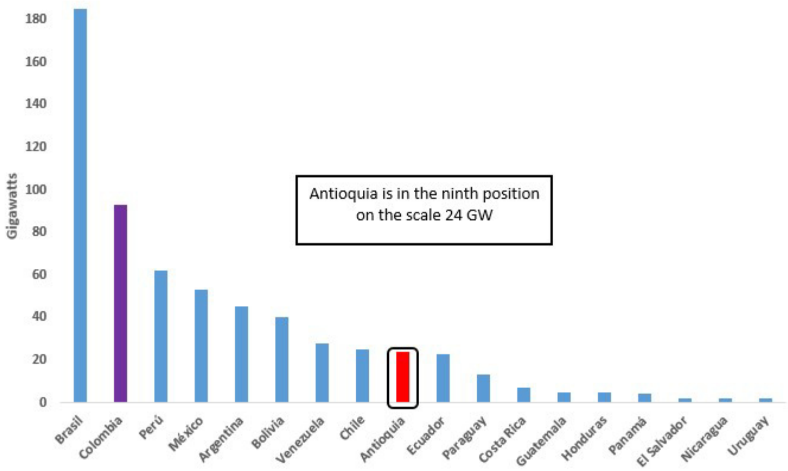
Figure 4. 2010 Antioquia's hydroelectric potential: development phase.



Source: The authors based on [14]

The following figure shows how Antioquia's 24 GW represents 4% of Latin American countries' total potential, being Colombia's 93 MW the 15%. Although Colombia, and particularly Antioquia, is considered a rich country regarding hydroelectric potential, there is an extensive amount of unexplored resources which can surely represent significant development possibilities in the future [14], [26].

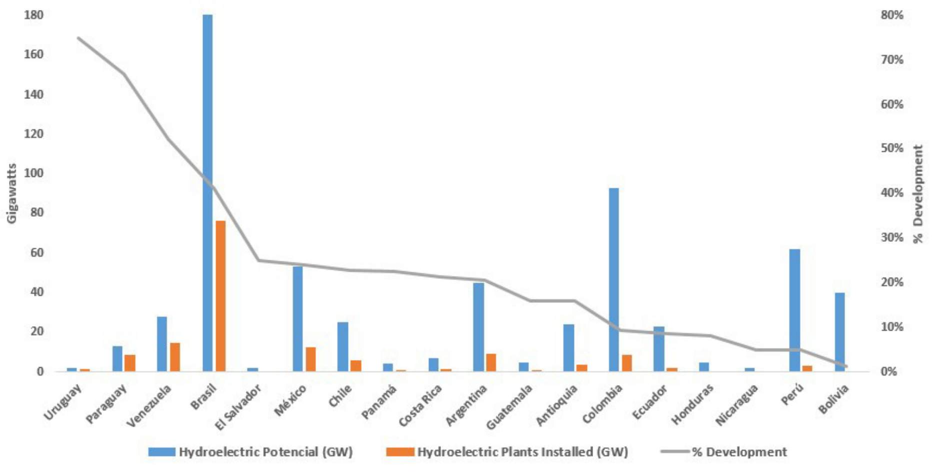
Figure 5. 2010 Hydroelectric potential in Latin America.



Source: The authors based on [14]

According to the Figures 5 and 6, Antioquia's hydroelectric potential is located in the middle of the scale, which is composed of 18 countries (Central and South America). This fact denotes the relevance Antioquia has in the Latin American context. Colombia's potential is only outshined by Brazil's. Moreover, Antioquia represents 26% of this Colombian asset (Antioquia itself, almost reaches Chile and Venezuela's ratios).

Figure 6. 2010 Hydroelectric potential in Latin America: development percentage and installed capacity.



Source: The authors based on [14]

Additionally, to all the benefits SHP projects have presented so far, there is the fact that the use of hydropower plays an important role in regional integration processes and lead to binational environmental initiatives.

4. Conclusions

Colombia has boundless opportunities of becoming a relevant actor in the global context due to its hydroelectric capacity and its feasibility of participating in the international carbon credit market through the sale of Certified Emission Reductions. This is encouraged by the domestic demand reduction commitments mainly made by the European Union and Japan. According to the analyzed projects, the Antioquia region in Colombia presents an emission reduction potential of 536,284 CO_2 annual tons for the case of small hydropower plants. During the first seven-year accreditation period of the Kyoto Protocol's commitment, Antioquia's potential income would represent US$ 22,523,928.

The analyses revealed that power density could be considered a limiting factor for SHP CDM projects. Another factor that strongly influences CDM's attractiveness for SHP projects is the connection to the grid. Plants in the Northern region are geographically isolated from the National Interconnected Electric System and provide greater GHG reduction emissions than the SHP projects connected to the grid. SHP plants contribute to the development and improvement of life quality in rural communities. It is proved that the development of a country or region is strongly linked to the availability of energy. Although Colombia has a vast hydropower potential, there are some barriers that limit the development of SHPs. The lack of specific incentives, policies, complications in administrative procedures and the perception that large hydropower centrals and fossil fuels provide enough diversity in the energy mix are the main barriers to the penetration of SHPs projects in Colombia. It is necessary to establish a robust regulatory framework and provide incentives in order to attract investors and exploit the enormous hydropower potential available in the country. Concerning rural NIZ, it is necessary to encourage its development by delivering the generated power to them.

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