Implementation of the ACM0002 Methodology in Small Hydropower Plants in Colombia Under the Clean Development Mechanism

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Abstract - Worldwide, power generation from fossil fuels is currently in jeopardy due to carbon dioxide emissions that directly influence the greenhouse effect and thus, climate change. This has led to seek or encourage the use of other sources of power generation, such as hydropower. Small Hydroelectric Plants (SHP) represent a suitable alternative for electric power generation in Colombia due to favorable conditions in its operation and the low environmental impact compared with other available energy sources in the country. SHPs, within the Clean Development Mechanism, are considered a source of clean energy with minimal impacts on the environment. This article presents a review of the existing methodologies for assessing greenhouse gas emissions and the implementation of the ACM0002 methodology in a SHP in Colombia, calculating an updated emission factor in the country. The results of this study show the potential for developing SHP projects thanks to the numerous mighty rivers which generate electrical power and contribute to sustainable rural development in Colombia.

Keywords: Carbon market, Clean Development Mechanism (CDM), Small Hydroelectric Plant (SHP), ACM0002, Emission factor.

1. Introduction

In the past three decades, the world has been experiencing the consequences of climate change due to the excessive use of fossil fuels and the high greenhouse-effect gas emission (GEG). This effect has led to the signing of treaties such as the Kyoto Protocol (KP); these have clear objectives on restricting greenhouse gas emissions to the developed countries and even to the developing countries [1].

From the climate change point of view, it is irrelevant where gas emissions are reduced because the effects on climate change occur (and its causes are fought) on a global scale [1]. However, from an economic point of view, it is more cost effective to reduce emissions where it leaves more economical to do so. These environmental changes occurring globally have raised the responsibility that they bear the nations, and especially the actors of the industrial and business sector as the main agents of this change [2], [3].

Taking into account this approach, the KP has promoted the Clean Development Mechanism (CDM) with two clear objectives: the first one is to provide assistance to countries within Annex I (list of developed countries and economies in market transition that signed the Kyoto Protocol) to fulfill their commitment with the Protocol. The second one states that, through the projects carried out in developing countries, the latter may benefit with the transfer of environmentally sound technologies provided by the most advanced countries and, therefore, sustainable development is conducive to such countries. The bonds (credits) generated through this mechanisms are known as "Certified Emission Reductions", CER by its English acronym [4]; they are awarded to projects that help reducing GEG emissions. These credits can be sold to industry actors as "permits" to emit higher quantities of GEGs than the ones allowed and then, trade them in the stock market as tradable carbon credits [5].

Latin America has become a major supplier of CDM projects in the world. This has been possible thanks to the implementation of the Kyoto Protocol, to the support from regional governments, to CDM project assessment committees, and to the presence of local experts in institutions promoting CDM projects. Among these carbon credit eligible projects, we can mention the hydroelectric plants [6].

Several authors have discussed the use of renewable energy systems instead of conventional energy systems in CDM projects. They have also discussed about their social, economic and environmental impacts, showing trends towards the overall reduction in emissions as a result of the installation of renewable energy systems in remote areas [7]–[13].

On the other hand, other studies [10], [14]–[17] have evaluated small hydropower projects (SHP) as candidates for GEG emission reduction. It is shown that renewable energy technologies such as SHP can contribute to global sustainability through the mitigation of GEG [9], [18]. Furthermore, studies conducted in developing countries show that investing in more efficient technologies, the rational use of energy and the replacement of fossil fuels with renewable ones can significantly reduce the emissions of greenhouse gases. Since SHPs represent a source of renewable energy reducing GEG emissions, it is likely that the CDM market is a source of opportunity for their development, increasing investors' interest in this type of energy sources [19].

Any SHP, depending on its implementation details, may be configured as a CDM, since it is an alternative for the generation of clean, renewable electric Energy [14]. Although several authors argue that SHP causes little or no environmental impact, and might be considered a source of clean energy [20], [21]. According to Purohit [22], "Small Hydro Power (SHP) projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development, if developed correctly". These projects also have additional benefits for sustainable development and are favored by some carbon credit dealers because it is easy to determine their base line [23], [24].

Colombia, and particularly Antioquia, offers a high good quality hydroelectric potential thanks to the successful combination of its high-flow hydric sources, its environmental policies, abundant topographical falls and stable underground geological conditions [18], [25]. It also has acceptable road and electrical infrastructures that facilitate connectivity and access to the project areas; this allows the transport of the energy produced. These features allow hydroelectric power plants in Antioquia to run sustainably and to benefit from carbon credit issuing, without negatively affecting the environment.

In order to quantify the carbon credits, the methodologies approved by the United Nations Framework Convention on Climate Change (UNFCCC) can be applied; they include the fulfillment of standards such as the type and size of the project, the source of energy used and the sectors involved [26]. These methodologies are, in short, economic valuation of emissions models that determine the emission reduction potential of a project.

This paper seeks for reviewing and implementing some of the existing methodologies for economic valuation of reduced emissions in the hydroelectric generating plant "Generadora Alejandría" and its impact on the Colombian electricity sector. Given this scenario, SHP constitutes a very interesting opportunity for sustainable development in Colombia.

2. Materials and Method

2.1. Methodologies for valuing emissions

From an exploration of the methodologies approved by the UNFCCC, 66 methodologies for evaluating emissions were found. These include the types of projects and eligible technologies such as the Clean Development Mechanism. The implementation areas include the energy sector (generation, distribution and consumption) as well as the manufacturing, construction, transportation, mining, metal, waste management, and reforestation industries. The review found that the most popular projects to be approved under the CDM scheme are the ones on renewable energy with 56% of the traded market share. Within the latter, hydroelectric plants are the most common representing 26% of the total registered projects in the early 2012 [26].

The existing methodologies present the following classification according to the CDM's Executive Board:

Approved Methodologies (AM): They constitute the largest methodology group approved by the CDM's Executive Board. Initially, these methodologies are developed by an exponent for a specific project, but they can be used for other projects with the same conditions of applicability.

Approved Consolidated Methodology (ACM): It is a large-scale methodology for calculating emission reductions for a project, whose use is approved by the CDM's Executive Board. It is consolidated from a number of approved methodologies (AM); a consolidation into a single methodology from a large number of methodologies for similar or related projects. The consolidation is carried out by the UNFCCC and not by the project proponents.

Approved Methodology for Small Scale Project Activities (AMS): There are methodologies available for small-scale project activities, which provide baseline methodologies and simplified monitoring. Methodologies have being developed differently from the large-scale ones; their development occurs in a descendent way from the CDM's Executive Board. It has not been necessary for the Project participants to present them.

Each methodology is applied depending on the type of project. The UNFCCC has differentiated the projects into three groups:

i. *Regular or large-scale projects.*

They are categorized according to Table 1.

Table 1. Categories of large-scale projects [2]

No.	Name of category
1	Energy Industry (from renewable and non-renewable sources)
2	Power distribution
3	Power demand
4	Manufacturing Industries
5	Chemical Industries
6	Construction
7	Transport
8	Mining/mineral Production
9	Metal Production
10	Fugitive fuel Emissions (solid, gas y oils)
11	Sulphur hexafluoride and halocarbon Fugitive Production Emissions and Consumption
12	Use of solvents
13	Waste management and disposal
14	Forestation y reforestation
15	Agriculture

ii. *Small Scale Projects.*

They are classified according to Table 2.

Table 2. Categories of small-scale projects [2]

Type	Name of Category
I	Projects with renewable energies
II	Projects on improving power efficiency
III	Other projects

iii. *Afforestation and reforestation projects:*

Although afforestation and reforestation are a subtype within the Large-scale Projects, the development of such projects (methodologies, emission certification, type of reductions, periods for certification, eligibility, etc.) is substantially different since these projects deal with carbon sequestration not with emission reduction. This is why they have a special category: Baseline Methodologies and Monitoring specifically for afforestation and reforestation projects.

In the particular case of the power sector, different methodologies have been developed. These methodologies are, in short, economic valuation models for determining the emission reduction potential of a project. Table 3 describes the main methodologies applied to this sector. It outlines the methodologies used in the power industry, especially those related to their implementation in hydroelectric plants (as sources of renewable energy). Table 4 shows a detailed characterization of the most applied methodologies in hydroelectric projects and their implementation conditions.

2.1.1 Methodology ACM0002 and its application in hydroelectric projects

The way the lines forming the scenarios with and without a project are determined depends on the type of project proposed. The methodology ACM0002: “Consolidated methodology for grid-connected electricity generation from renewable sources” estimates the emission reductions attributable to projects that generate electricity from renewable sources, including water. The essential question that this methodology seeks to answer is: ¿How does the inclusion of a renewable source of energy affect an interconnected system? While there is no exact way to determine this impact, the methodology uses as an approach, the influence of such plants in the dispatch order of the interconnected systems. Specifically, the ACM0002 defines its baseline, as "the electricity that, in the absence of a proposed project, would be provided by the plants currently connected to the network or adding new ones to this network" [28].

The idea behind this definition is simple: renewable energy sources usually have a lower marginal cost than thermal power stations (which depend on more expensive fuels), which is why the first tend to relegate the second ones to lower priority in the dispatch’s merit order [4], [7]. Thus, incorporating a plant generating 1,000 MWh of energy from renewable sources (generally with a low marginal cost) will tend to displace 1,000 MWh that would have been generated by gas, coal or diesel plants. The methodology ACM0002 is constructed from this simplification, observing fossil fuel plants consumption precisely from the higher marginal cost plants. Depending on the type of fossil fuel consumed there will be greater or lesser amount of CO2 emissions. Following this approach, the methodology allows calculating the emission factor (EF) of the electric network; that is, how many tons of carbon dioxide (tCO2) are emitted on average for each MWh of energy generated [28].

2.1.1.1 Methodology for the Baseline

The consolidated methodology establishes that the baseline of a power generation activity from renewable sources is based on the calculation of two necessary variables; they estimate the emission reductions of a project. These two variables are the emission factor operating margin (EFOM,y) and the build margin emission factor (EFBM,y). The Operating margin represents the effect of CDM activity over the dispatch and power plants connected to the national electricity system where the activity operates. The build margin characterizes the effect of CDM activity on generation capacity additions to the system where the activity operates. Based on a weighted average of these two margins, the emission factor of the baseline (EF,y) is obtained [28]–[30].

The consolidated methodology provides four options for calculating the (EFOM, y):

- Option A. Simple Operation Margin (Simple OM)

- Option B. Simple Adjusted Operation Margin (Simple Adjusted OM)
- Option C. Operating Margin with dispatch data analysis (Dispatch Data Analysis OM)
- Option D. Average Operation Margin (Average OM)

The methodology also states that the method selected in the first instance must be C. That is the operating margin with dispatch data analysis [28]. The other three options can be chosen by the proponents of the project, only after having justified the impossibility or inconvenience of method C. Option A can only be used in electrical systems in which hydroelectric generation accounts for less than 50% of the energy generated. Provided that time information on offers and generation is available in Colombia by consulting the information system NEON (National Dispatch Center),then Option C is mandatory in the country: "Dispatch Data Analysis OM" [31].

The methodology also defines two alternatives for the calculation of the build margin emission factor (EFBM, y):

- Option 1. Build Margin calculated *ex-ante* and fixed for the accreditation period.
- Option 2. Build Margin calculated *ex-post* and updated annually during the first accreditation period, and calculated *ex-ante* and fixed during the following periods of accreditation.

2.1.1.2 Methodology for the Emission Factor

The emission factor (tCO2 / MWh) of the power network to which the project is connected can be calculated according to the "Tool to calculate the emission factor for an electricity system". According to this tool, the network's emission factor corresponds to the weighting of two factors: (i) The Operating Margin is an emission factor reflecting the effect of the CDM project on the group of existing plants whose generation power would be affected. (ii) The Building Margin is an emission factor representing the effect of CDM project on the construction and start-up of new power plants.

The methodology presented in this paper shows several activities that can be arranged as follows:

- Step 1. To identify the relevant power system.
- Step 2. To decide whether the generating plants that are not connected to the network are included (optional).
- Step 3. Select the method to determine the operating margin.
- Step 4. To calculate the operating margin's emission factor according to the selected method.
- Step 5. To identify the set of generating units to be included in the build margin.
- Step 6. To calculate the build margin's emission factor.
- Step 7. Calculate the combined margin's factor.

Table 3. Categorization of methodologies in the energy sector [27]

Sector	**Type**	**Power Generation and Distribution**	**Energy for Industries**
1. Energy Industry (Renewable and non-renewable sources)	Renewable energy	AM0007 AM0019 AM0026 AM0042 AM0052 AM0100 ACM0002 ACM0006 ACM0018 ACM0020	AM0007 AM0036 AM0053 AM0069 AM0075 AM0089 ACM0006 ACM0020 ACM0022
	Power generation	AM0029 AM0045 AM0074 AM0087 AM0099 M0104	AM0087 AM0099
	Power efficiency	AM0014 AM0048 AM0049 AM0061 AM0062 AM0076 AM0084 AM00102 AM00107 ACM0006 ACM0007 ACM0012	AM0014 AM0048 AM0049 AM0061 AM0055 AM0056 AM0076 AM0084 AM0095 AM0098 AM0107 ACM0006
2. Power Distribution	Renewable energy	AMS-III.AW AMS-III.BB	AM0069 AM0075
	Power efficiency	AM0067 AM0097 AMS-II.A AMS-III.BB	
3. Power Demand	Power efficiency	AMS-III.A	AM0017 AM0018 AM0020 AM0044 AM0060 AM0068 AM0088 AM0105

Table 4. Most used methodologies for hydroelectric projects [27]

No.	NAME	TYPICAL PROJECTS	CONDITIONS
AM0019	"Renewable energy projects replacing part of the power production from one single fossil fuel fired power plant that stands alone or supplies to a grid, excluding biomass projects"	Building of a renewable power plant (excluding biomass).	Plants with a dam and power density higher than 4 W/m2
AM0026	"Methodology for zero-emissions grid-connected power generation from renewable sources in Chile or in countries with merit order based dispatch grid"	Power generation projects from renewable sources such as hydroelectric, biomass, geothermic, solar, wind and waste management.	Plants with a dam and power density higher than 4 W/m3
AM0052	"Increased power generation from existing hydropower plants through Decision Support System optimization"	Increased Annual generation through implementing a DDS system connected to network.	Plant must be optimized through a Decision Support System DSS
ACM0002	"Grid-connected power generation from renewable sources"	Adaptation, substitution or additions to an existing power plant's capacity or the construction and operation of a power plant that uses renewable sources and supplies power to networks. Run-of-river projects.	The methodology cannot be implemented in projects replacing fossil fuels at the project place nor in biomass-operated plants
AMS-I.D	"Grid-connected renewable power generation"	Renewable power generation units such as photovoltaic, hydroelectric, wave, wind, geothermic and biomass.	Special criteria applied to hydroelectric projects with dams.

2.2. Small Hydro Power 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 for industrialized countries. SHP projects could be of interest under the CDM because they directly displace greenhouse gas emissions while contributing to sustainable rural development [22]. CDM has certainly brought renewable energy into the world's focus on sustainable development. The key feature of this mechanism is that the developed world sets its emission reduction targets and the developing world can benefit from the implementation of clean energy technology. 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 its environmentally benign nature. The sale of CERs could help to accelerate sustainable development for the SHP projects 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''[32]. Sustainable development is a remarkable paradigm based on these three pillars. Balancing these three aspects in order to meet our needs today will have a large impact on our future generations [33].

According to the US President's Council on Sustainable Development, ''Economic growth can and should occur without damaging the social fabric of a community or harming the environment'' [33]. Environmental sustainability is ''a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity'' [34].

Another important aspect of sustainability called "social sustainability" is the development that promotes social cohesion. According to the Western Australia Council of

Social Services, ‘‘Social sustainability occurs when the formal and informal processes; systems; structures; and relationships actively support the capacity of current and future generations to create healthy and liveable communities [32].

SHP projects bring many types of benefits to the surrounding communities. Villages not only get electrified but also these plants also generate employment, promote small-scale industries and improve infrastructures. Reduced migration of local people, the establishment of schools, parks and hospitals are other benefits that these projects bring in.

2.3. Case Study: Hydroelectric Project: Generadora Alejandria

The following is the ACM0002 methodology for hydroelectric project Generadora Alejandria. A similar analysis has previously been presented in [35]. However, this paper makes a more detailed and updated analysis of the implementation of the methodology in the Colombian case.

2.3.1. Overview of the project activity

The hydroelectric project Generadora Alejandria, to be developed in the coming years, is located in the province of Antioquia in Colombia, near the municipalities of Alejandria, Concepción and Santo Domingo. Its area of influence includes the hamlets of Remolinos (in Alejandria), Fatima (in Concepcion) and Los Naranjos (in Santo Domingo). The project will generate 15 MW using the Nare river basin.

The purpose of this project is to generate additional electricity to Eastern Antioquia and contribute to the sustainable development of the region and the country by reducing CO2 emissions; this statement is reflected in the following:

1. This initiative is in line with a new trend to promote the construction of small hydropower plants in the country. These plants contribute to sustainable development with few resources in different parts of the country.
2. Plants of this type contribute to the reduction of pollutants in the country, contrary to thermoelectric plants.
3. Great knowledge and national experience can be learned from the construction of such type of projects like the development of national institutional capacities aimed at strengthening competitive advantages to participate in the international carbon market.
4. The closest community to the project can get additional benefits from the sale of environmental services generated by the project.

The project activity reduces CO2 emissions in the generation of electricity using renewable energy sources. It also replaces the fuel consumed by the fossil fuel plants (a combination of coal and gas based power plants in the National Interconnected System of Colombia) with clean energy provided by hydropower. The inclusion of the project in the System’s grid redistributes the power dispatch to all power plants, which results in a more efficient generation of electricity of the entire system.

2.3.2. Name and reference of the approved methodology for the baseline and monitoring applied to the project activity

According to Colombia's energy matrix, the type of data available and the activity of the CDM itself, the proposed project was developed using the baseline methodology ACM0002 / Version 13.0.0 “Consolidated methodology for grid-connected electricity generation from renewable sources” [28].

2.3.3. Description of the sources and gases included within the project

As mentioned in ACM0002 - version 13.0.0, the project’s limits should be evaluated in terms of emission sources and spatial extent. Table 5 shows the greenhouse effect gases included in the project.

Table 5. Description of the sources and gases included within the project

	Source	Gas	Inclusion	Justification
Baseline	CO_2 emissions from fossil fuel electricity generation that are displaced due to the project activity.	CO_2	YES	Main source of emission. The thermic units in the grid produce GEG emissions that are avoided when the project’s activity enters the grid, replacing the thermic units.
		CH_4	NO	Minimum source of emission
		N_2O	NO	Minimum source of emission
Project’s activity	For hydroelectric plants, including run-of-river plants without a dam; CH_4 emissions are not considered.	CO_2	NO	Minimum source of emission
		CH_4	NO	No dam
		N_2O	NO	Minimum source of emission

2.3.4. Justification of the selected methodology and its implementation in to the project’s activity

Due to the project’s activity, the methodology ACM0002 version 13.0.0 can be implemented due to the following reasons: i) The proposed project is for electricity generation using renewable energy sources; it supplies the electricity grid. ii) The project does not involve the shift from fossil fuels to renewable energy at the site of the project's activity. iii) The geographical boundaries and the power supply system of the Colombian grid can be clearly identified and there is available information on the characteristics of the network [15], [30], [36], [37].

Due to the fact that the project is a hydroelectric plant, the methodology determines that the project is "zero" CO2 emissions [10], [28].

2.3.5. Description of the baseline scenario's identification

Colombia's Interconnected System (SIN) is a system of hydrothermal electricity with a Net Effective capacity of 15,478MW (2014); it is dominated by hydropower (69.6%) and composed in a lesser extent by thermal plants (25.26%) and other sources (5.14%).

The baseline for the hydroelectric project is defined by the electricity dispatched to the grid by the project, which would have been generated by the grid-connected plants and by the addition of new sources, as reflected in the combined margin calculations (CM).

Therefore, the baseline scenario is one where the electricity that could be provided by the project to the network would have to be generated by other plants currently connected to the national grid and by adding new plants to the system, based on different types of fuels. Therefore, the generation of the national grid presents lower CO2 emissions than the ones occurring without the project.

For this type of initiatives using renewable energy, the CO2 emissions during the operation phase of the project are not considered [28]. However, several authors [12], [16], [22], [38]–[40] have shown that the emissions generated particularly in the implementation phase of the project (construction, fuel handling, flooding of land) are considerable.

3. Results and Discussion

3.1. Calculation of emission reductions prior to project implementation (ex-ante)

The baseline scenario emissions correspond to CO2 emissions associated with the consumption of fossil fuels that have been used by power generation plants that are displaced by the CDM project. To this end, the UPME, on its official website, reports a CO2 emission factor from the Colombian SIN of 0.2849 tCO2 / MWh; it was calculated from the information available in 2008 [31]. For this case, this emission factor will be recalculated with the available market information in order to carry out a study with updated values, as illustrated later in this section.

The baseline emissions are calculated as the product of the emission factor (tCO_2 / MWh) of the grid and the net energy dispatched by the project's activity.

$$BE_y = EG_{PJ,y} \times EF_{grid,CM,y} \quad (1)$$

BE_y = Baseline emissions in year *y* (t CO_2/yr)

$EG_{PJ,y}$ = Net quantity of power generation produced and transmitted to the grid as a result of the implementation of the CDM project's activity in year y (MWh/yr).

$EF_{grid,CM,y}$ = Emission factor of the grid, calculated as the average of the operating margin's emission factor ($EF_{OM,y}$) and the emission factor of the build margin ($EF_{BM,y}$), (t CO_2/MWh).

Then, the emission factor is calculated by the procedure described in 2.1.1.1:

Step 1. *To identify the relevant power system.*
The national grid is used.

Step 2. *To decide whether the generating plants that are not connected to the network are included (optional).*
It is decided to include only power plants in the project's power system.

Step 3. *To select the method to determine the operating margin.*
The calculation of the operating margin's emission factor is based on the Simple Adjusted OM method. The data selected for this calculation correspond to an average of the last three years of generation (based on the most recent data available).

Step 4. *To calculate the operating margin's emission factor according to the selected method.*

The Simple Adjusted OM emission factor is calculated as CO2 emissions per unit of net power generation (tCO2 / MWh) from a combination of low-cost / must-run plants (this term is widely used in the literature and refers to inexpensive plants that should be included in the system), power (k) and other power plants (m), as shown below:

$$EF_{OM-Adj,y} = (1 - \lambda_y)\frac{\sum_m EG_{m,y} * EF_{EL,m,y}}{\sum_m EG_{m,y}} + \lambda_y \frac{\sum_k EG_{k,y} * EF_{EL,k,y}}{\sum_k EG_{k,y}} \quad \textbf{(2)}$$

Where:

$EF_{OM-Adj,y}$ = The simple adjusted operation emission margin in year *y* (t CO_2/MWh)

λ_y = The factor expressing the percentage of times when the power units low-cost/must-run meet in the margin in year *y*

$EG_{m,y}$ = Net amount of generated electricity and delivered to the network by unit *m* in year *y* (MWh)

$EG_{k,y}$ = Net amount of generated electricity and delivered to the network by unit *k* in year *y* (MWh)

$EF_{EL,m,y}$ = CO_2 emission factor per power unit *m* in year *y* (t CO_2/MWh)

$EF_{EL,k,y}$ = CO_2 emission factor per power unit *k* in year *y* (t CO_2/MWh)

m = All units connected to the grid except the power units low-cost/must-run

k = All power units low-cost/must-run connected in year *y*

Parameter λ_y is defined in the following way:

$$\lambda_y = \frac{plants\ hours\ low-cost/must-run\ in\ margin\ in\ year\ y}{8760\ hours\ for\ year} \quad \textbf{(3)}$$

To calculate the value of lambda, the following procedure is required [28]:

• To collect chronological power data for each hour of year *y*, and sort load data from the highest to the lowest and plot them on a bend in descending order.

• To calculate the total annual generation (kWh) of energy plants / low-cost / must-run units.

• To draw a horizontal line across the power duration curve such that the area under the curve is equal to the total production (in kWh) of the low-cost / must-run units.

• To determine the number of hours that the low-cost / must-run sources are on the margin in year y.

Figures 1 to 3 show the results obtained for calculating the parameter lambda.

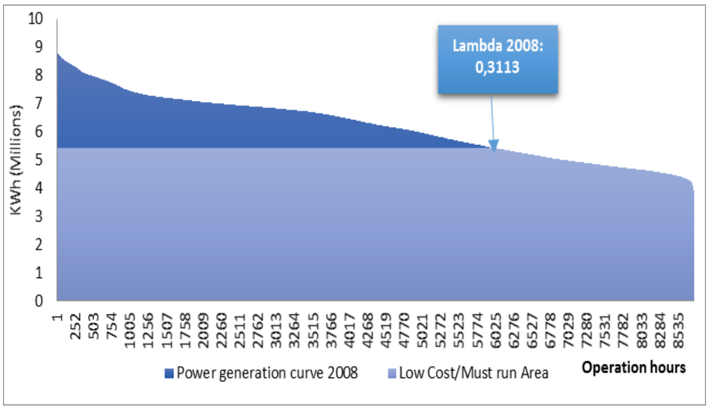

Fig. 1. Calculation of lambda in 2008

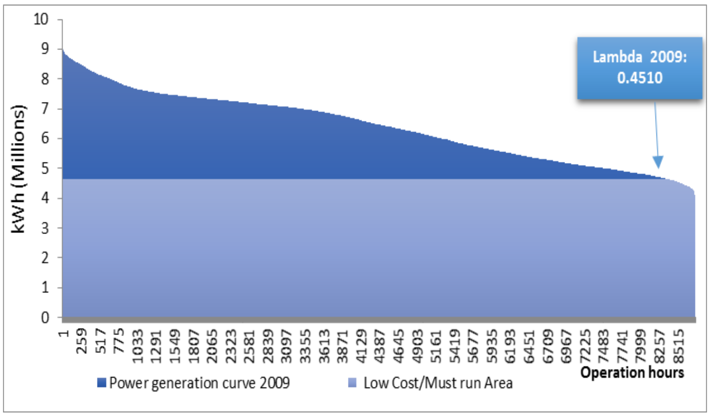

Fig. 2. Calculation for lambda in 2009

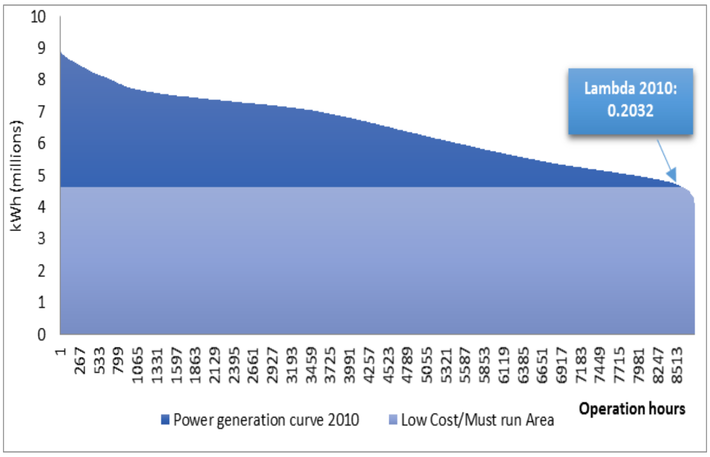

Fig. 3. Calculation for lambda in 2010

To calculate CO_2 $EF_{EL,m,y}$ y $EF_{EL,k,y}$ emission factors, the following equation is required:

$$EF_{EL,m,y} = EF_{CO2,i,m,y} * \eta_{m,y} * CONV \quad \textbf{(4)}$$

Where:

$EF_{CO2,i,m,y}$ = The CO_2 emission factor fuel type *i* used by plant *m* in year *y* (t CO_2/TJ)

$\eta_{m,y}$ = Efficiency of fuel from plant *m* in year *y* (MBTU/MWh)

$CONV$ = 1 MBTU = 0.001055056 TJ conversion factor

i = Type of fuel used by plant *m*

The calculated set of emission factors from power unit n ex-ante shall be reviewed early the next crediting period based on official data and the public's availability.

Table 6 shows the values of the emission factor for each type of fuel used in power plants, as set by the methodology for the calculation of CO_2 emission factors. Table 7 shows the results obtained from "equation (3)" for calculating the CO2 emission factors per power unit.

Table 6. Emission factors by fuel source [41]

Type of plant	**Fuel**	**IPCC 2006 Fuel EF (kgCO_2/TJ)**	**TJ/MBTU**	**tCO_2/ MBTU**	**Fuel EF tCO_2/ MBTU**
Hydroelectric	-	-	-	-	0
Gas-run thermic plant	Natural gas	54.300	0,0010545	0,057259	0,05726
Coal-run thermic plant	Bituminous coal	89.500	0,0010545	0,094378	0,09438

Table 7. Emission factors by fuel source

VARIABLE	2008	2009	2010
Low cost/Must run (kWh) power generation	45,984,245,807	40,677,087,860	4,.503,285,282
Low cost/Must run (tCO_2) emissions	16,355	33,180	73,224
Low cost/Must run (tCO_2/MWh) OM	0.0003557	0.0008157	0.0018078
No Low cost/Must run (kWh) power generation	8,128,306,238	14,964,392,812	16,068,818,044
No Low cost/Must run (tCO_2) emissions	5,326,893	10,951,971	10,338,353
No Low cost/Must run OM	0.6553509	0.7318687	0.6433798

Step 5. *To identify the set of generating units to be included in the build margin.*

The most used sample of generating plants to calculate the build margin correspond to the set of capacity additions in the power system, which comprise 20% of the generation (in MWh) and have been recently built [42], [43]. The sample helped determining the build margin emission factor obtaining results for this factor: 0.24422 t CO2 / MWh.

Step 6. *To calculate the build margin emission factor.*

The build margin emission factor is the emission generation factor (tCO2 / MWh) averaged from all m power units during the last year for which power generation data are available; it is calculated as follows:

$$EF_{BM,y} = \frac{\sum_m EG_{m,y} * EF_{EL,m,y}}{\sum_m EG_{m,y}} \quad \textbf{(5)}$$

Where:

$EF_{BM,y}$ = Build margin emission factor in year *y* (t CO_2/MWh)

$EG_{m,y}$ = Net amount of power generated and delivered to the grid by unit *m* in year *y* (MWh)

$EF_{EL,m,y}$ = CO_2 emission factor per power unit *m* in year *y* (t CO_2/MWh)

m = All units connected to the grid except low-cost/must-run power units

Table 8 presents the results for this calculation.

Table 8. Obtained results obtained from the calculating the build margin (BM) emission factor

CALCULATION VARIABLE	RESULT
Total Generation 2010 kWh	56,897,333,441
20 % of total generation 2010 kWh	11,379,466,688
Generation of 5 last plants kWh	205,723,335
20% of 5 last plants' generation kWh	11,748,551,458
BM 2010	**0.24422218**

Step 7. *To calculate the combined margin.*

From "equation (2)", the results of calculating the emission factor are obtained; as shown below.

Table 9. Results obtained for calculating the combined margin factor

VARIABLE	2008	2009	2010
No Low cost/Must run OM	0.6554	0.7319	0.6434
Low cost/Must run OM	0.0004	0.0008	0.0018
Lambda	0.3113	0.0451	0.0203
$EF_{OM;y}$	0.4514	0.6989	0.6303
Generation [MWh]	54,112,552	55,641,481	56,572,103
EF OM Simple and adjusted [tCO2/MWh]	**0.45589**		
$EF_{BM\ 10}$ [tCO2/MWh]	**0.24422**		
EF_{CM} [tCO_2/MWh]	**0.350058**		

The value obtained for the combined margin emission factor is 0.350058 tCO2 / MWh. From this data, the project's emission reduction can be estimated.

3.2. Summary of the ex-ante estimation of the project's emission reduction

For the first crediting period (seven years), implementing the CDM project will reduce 242,592 tonnes of CO_2 emissions. This would allow to obtain additional income in the carbon market, as payment for environmental services. Below, in a simplified way, there are the data obtained from the estimated reductions for the hydroelectric project. Table 10 shows the summary of the estimated emission reductions for the hydroelectric project Generadora Alejandría based on the data above.

Table 10. Calculation of the estimated emission reductions for the hydroelectric project *Generadora Alejandría* in 21 years' time.

CER (tCO_2e)	Baseline emissions (tCO_2e)	CER
7 YEARS	242,592	242,592
14 YEARS	485,184	485,184
21 YEARS	727,776	727,776

3.3. Expected revenues from the sale of bonds

There is a consensus that the sale of GEG emission reduction certificates increases the Internal Rate of Return (IRR) of the projects. At the same time, it can facilitate its financing due to the high quality of the cash flow generated by the sale.

In a simplified form, the net income of a CDM project from CER sales is estimated by the following equation:

$$I = V * P - T \quad (6)$$

where:

V = CER volume (t CO_2)

P = Price in the market (US$/ t CO_2)

T = Transaction costs

Given the current market characteristics, each of these variables can change significantly over time; it is due to both internal and external factors to the project itself. Therefore, any estimation regarding revenues will inevitably be absolutely referential.

Given the above, Figure 4 shows the possible revenues generated by Generadora Alejandría from three scenarios depending on the selling price of a ton of CO2: 3, 4 and 5 dollars; that, according to the current international market provided by CER purchases made by the World Bank.

3.4. Analysis of results

According to these results, in the first crediting period (seven years) of the project, reduced emissions would equal 242,592 tCO2e and the income from CER sales would reach USD $ 774,332 (in a conservative scenario considering the lowest price of CER in the market).

Remarkably, according to the destination of such additional income, a higher amount can be obtained from CERs in the market based on an investment proposal in the community to be intervened by the hydroelectric project. Therefore, the implementation of the ACM0002 methodology in the SHP Generadora Alejandría represents a proposal which (from an economic point of view) increases the financial profitability of the project. Moreover, such additional revenues can be allocated to meet the required investment in the environmental management plans, according to the Colombian law.

These data would have been different if the UPME's calculated emission factor had been used. According to the above, the hydroelectric project would have obtained CERs worth 169,244 tCO2e; it would represent a reduction of 30.23% on the projected revenues compared with the data calculated for the EF in this paper.

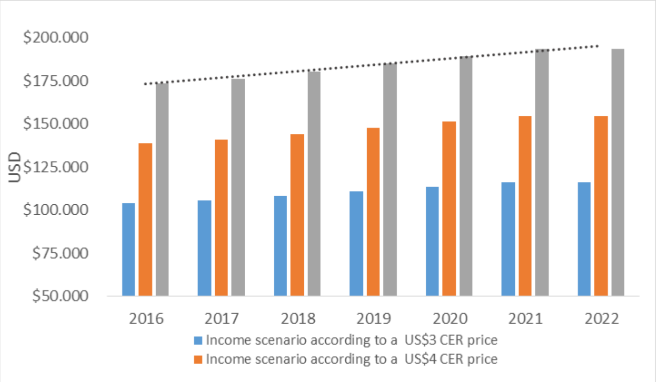

Fig. 4. Projected income from CER sales by the hydroelectric project *Generadora Alejandría*.

4. Conclusions

This article presents a review of the existing methodologies for valuing greenhouse gas emissions under the Clean Development Mechanism (CDM) approved by the UNFCCC as established in the Kyoto Protocol. The review emphasizes the methodologies related to power generation from renewable sources, and particularly those related to the operation of hydroelectric plants. It also presents the existing comparative advantage between certifying small hydropower projects (below 19 MW) in the CDM with respect to large hydroelectric plants thanks to the high feasibility of requirement compliance.

For implementing the ACM0002 methodology to the case study, it was necessary to calculate Colombia's emission factor. This article presents an updated emission factor contrasted to the one found in the UPME's official website, which only calculates the year 2008. Therefore, more accurate results can be generated; results in accordance with the current market perspectives. Thus, higher revenue than the one expected can be produced. In addition, the calculation of the emission factor allows the implementation of the ACM0002 methodology for any small hydroelectric plant in Colombia leading to a more expeditious analysis of such studies.

Taking into account the results of implementing the ACM0002 methodology in the Generadora Alejandría project, it can be stated that there are great possibilities for Colombia to participate in the carbon market through small hydroelectric plants. In turn, the hydroelectric projects seeking to contribute to local sustainability can find in the CDM a way to complement stable sources for financing.

Colombia has boundless opportunities of becoming a relevant actor in the global context due to its hydroelectric capacity for Small Hydro Power and its feasibility of participating in the international carbon credit market through the sale of Certified Emission Reductions. Small hydropower 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 generations which pollute the environment.

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