Methodological proposal for risk management in new small hydroelectric power plants SHPPs in Colombia

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Abstract: Colombia has more than 100 years of experience developing Large Hydropower projects including connected Risk Management (RM), which is very sensitive to technical and financial issues, but Non-Conventional Renewable Energy Sources (NCRES) is a relatively a new term in Colombia with no documented RM. This paper develops a methodological proposal based on PMBOK, ISO and Colombian Technical Standards, that will allow to identify, assess and manage the risks inherent in Small Hydroelectric Power Plant (SHPP) projects. All this in the context of the opportunities generated by Law 1715 of 2014 and the mega global trend of transition from fossil sources of energy to NCRES. The methodology was built based on: state of the art review; a literature research on specialized data bases; expert's knowledge consultation from a list of experienced Colombian companies involved on SHPP projects; Delphi technique and expert's analysis and assessment. The result is a methodology that includes: holistic identification of risk variables in SHPP projects, assessment of experts, response to inherent and residual risks. It leaves a benchmark of risk management for investors in this type of projects in Colombia.

Key words: Renewable energy, Small hydro generation, Small Hydroelectric Power Plant (SHPP), Non-Conventional Renewable Energy Sources (NCRES), Risk management, ISO31000

1. Introduction

United Nations' 17 Sustainable Development Goals, stated on its 7th goal, that sustainable energy development is an opportunity to ensure access to affordable, reliable, sustainable and modern energy for needed people living on developing countries (Kates, Parris, & Leiserowitz, 2016). The increase in the use of fossil fuels combined with the increase in the global population has caused that earth resources are getting closer to a dangerous point of no return for life as known, which is recognized as one of the social problems of our time by key scientists, politicians and religious leaders at a global level. Citing the top leader of the Catholic church: "There are not just two separate crises, an environmental and a social one, but just one and complex socio-environmental crisis" (Pope Francis, 2015). The effect of the abuse of fossil fuels on the environment is devastating. The most frightening aspect is the fact that in recent decades of this new century, the consumption of fossil fuels has increased. This has contributed to the emission of greenhouse gases and the release of pollutants in the atmosphere that has serious

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consequences, including global warming. Therefore, it is necessary to protect planet Earth through the incorporation of renewable energy sources, which are respectful to the environment.

In the local Colombian context, factors such as: energy sovereignty, the phenomenon of "El Niño" (Collins, An, & Cai, 2010), (Cai & Borlace, 2014) & (Hoyos, Escobar, Restrepo, Arango, & Ortiz, 2013), the exhaustion of energy fossil fuels, and specifically the dramatic decrease of natural gas reserves (Mining and Energy Planning Unit of Colombia; UPME, 2016a). As well as to meet the commitments made by Colombia at the Paris Climate Change Summit(García Arbeláez, Barrera, Gómez, & Suárez Castaño, 2015), which are comparable with those of other countries in the region and that sets forth the 20% reduction of its greenhouse gas emissions by 2030; the country shall promote the use of NCRES (Gualteros & Hurtado, 2013), as well as a more efficient energy management (Mining and Energy Planning Unit of Colombia; UPME, 2016b) (UPME, 2015) & (Pardo Martínez & Alfonso Piña, 2015). Project development of NCRES in Colombia has been leveraged by Law (LEY 1715, 2014), pursuant to which the integration of non-conventional energies (geothermal, wind, solar, biomass and SHPPs) in the National Energy System (SEN) is encouraged. This law has two objectives: a) to promote the development of non-conventional energy sources, integrating them to the national energy system, and b) to promote energy solutions to rural and isolated areas of the country. All efforts coordinated between academia, and the electricity industry to improve the effectiveness and efficiency of NCRES and particularly in the SHPP projects, its integration into the National Energy System are in line with the National Government's energy sovereignty objectives (Departamento Nacional De Planeación (DNP), 2017) & (Consorcio Energético CORPOEMA, 2010).

Risk management is one of the tasks in which investors and organization's management gets more directly involved and concern. In fact, the impact of Enterprise Risk Management (ERM) is measured in the performance of many organizations (Lai & Shad, 2017). The purpose of generating a guide for the ERM, as a controllable and streamlined "process" that formulates the path tasks and operations for functional areas of management, so that the risks identified do not curtail the company's strategic plans. It is like a key element for the contribution to the perdurability of organizations committed with the development of power generation projects of NCRES, which coincides with the guidelines of the Masters in Direction and Management at the Universidad del Rosario. This methodological proposal will be developed for those organizations that decide to include in in the corporate objectives of: innovation, environmental sustainability, actions against global warming, social sustainability, economic sustainability and optimization of energy resources by the development of SHPP projects in their strategic plants as a point of integration.

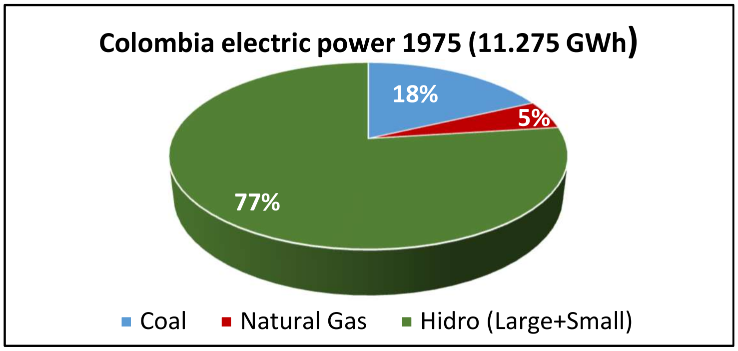
From all Non-Conventional Renewable Energy Sources (NCRES), Colombia has more than 50 years of experience developing Small Hydroelectric Power Plant (SHPP) projects, but risk management remains as the main concern among investors. Literature review shows that technical and financial issues have been covered, mainly for the transference of expertise from large hydropower projects to SHPP projects, but it is required an holistic point of view that discusses other variables such social and environmental that can deeply impact SHPP projects. Some SHPP projects execution have been seriously threatened by risks beyond technical and financial issues in Colombia. Thus, a complete perspective of RM that discusses other variables such social and environmental is required for NCRES projects. This shall to be done sorted by energy power source in accordance with the manner in which they are obtained: biomass, geothermal, from the sea, wind, solar and SHPP (S.R. Bull, 2001).

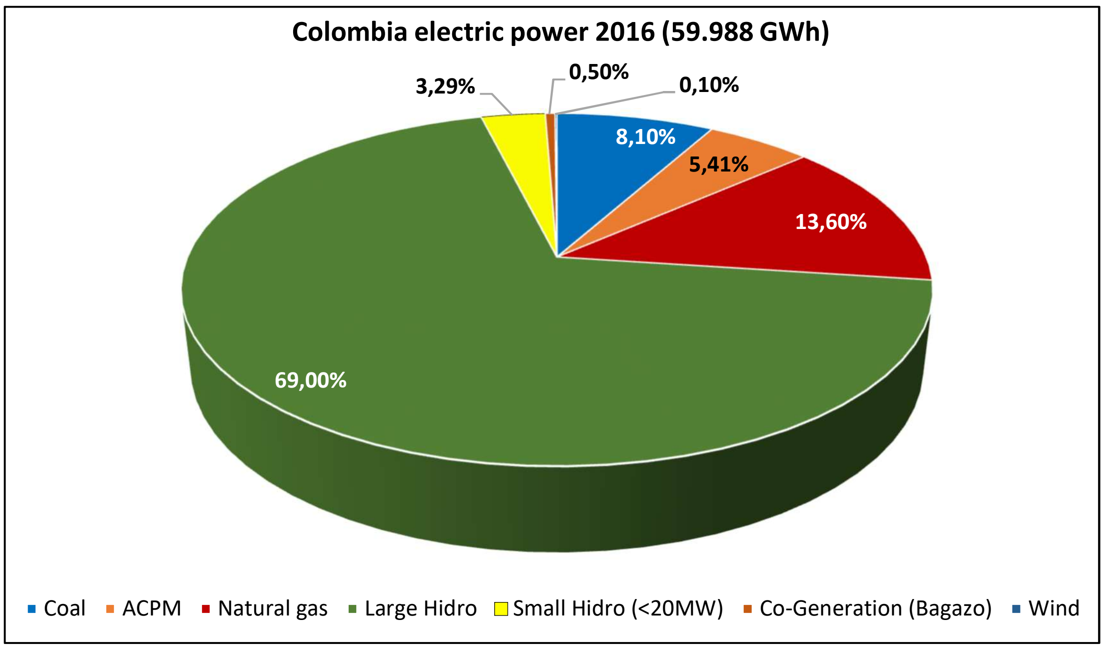
The main goal of this review paper is to present a methodological tool that allows to identify and analyze the main risks involved in the execution of generation projects in SHPPs (<10MW) in Colombia under the guidance of Colombian Technical Standards NTC5254 and NTC-ISO-31000-2011 (Icontec, 2004) & (Icontec, 2011). The contribution of this research consists on develop the first methodological proposal based on PMBOK, ISO and Colombian Technical Standards that will allow to identify, assess and manage the risks inherent in SHPPs projects in Colombia. This paper is organized as follows: in Section 2 the current state of Small Hydro Power Generation in Colombia and its associated risk management is presented. Section 3 briefly defines the methodology used to collect data. Section 4 presents the results of identifying, organizing and assessing risks. Finally, Section 5 reflects both the conclusions of the research as well as discussion of recommendations to resolve potential mitigations. Because of in Colombia a SHPP can last more than 2 years on feasibility phase a case study is not in the scope of this work. Because of in Colombia a SHPP can last more than 2 years on feasibility phase a case study will be on the scope of future researches.

2. Background of Small Hydro Power Generation in Colombia and Literature Review

According to UPME's 2011 report (Mining and Energy Planning Unit of Colombia; UPME, 2006) & (Mining and Energy Planning Unit of Colombia; UPME, 2016c) the composition of the production of Colombian electricity has multiplied by 5 in the last 35 years, as shown in **Figure 1**. This means that there has been a 15% annual growth, but unfortunately the diversification of the sources has been only 4.5%. The Colombian electric-energy sector has had several regulatory reforms. The most notable reform is the one that arose from the 1992 energy crisis because of the "El Niño" phenomenon. This crisis known as "The blackout", brought serious consequences to the country's agricultural and industrial production. Since then, regulations have been directed to: meeting the demand, at the lowest cost and guaranteeing the reliability of the supply (UPME, 2015) & (Mining and Energy Planning Unit of Colombia; UPME, 2016c)**.** As also shown in **Figure 1,** the generation sources in Colombia are concentrated in large technologies for hydroelectric power plants (with dams) and conventional thermal plants powered with both carbon and gas, which is worrisome with respect to the shortage of natural gas in Colombia within the next years (Mining and Energy Planning Unit of Colombia; UPME, 2006). In a positive scenario, the natural gas reserves offer autonomy until 2024 and in a crisis scenario, because of every eight years the "El Niño" phenomenon, there could be shortages by the end of 2018 (Mining and Energy Planning Unit of Colombia; UPME, 2016a).

Figure 1. Evolution electricity production in Colombia by source 1975-2016. Source: (UPME, 2015) & (Mining and Energy Planning Unit of Colombia; UPME, 2006)





On the other hand, from the seven technologies identified NCRES, the current composition of those that are interconnected to the National Interconnected System (SIN) in Colombia is as shown in **Table 1:**

Table 1. Participation of NCRES technologies with high installed capacity in Colombia, Source: (Renewable Energy Policy Network for the 21st Century REN21, 2016), (Mining and Energy Planning Unit of Colombia; UPME, 2006) & (Mining and Energy Planning Unit of Colombia; UPME, 2016c)

Technology	Current Installed Capacity (MW)	Market Share
SHPPs	719,57	93,9%
Biomass	26,9	3,0%
Wind	19,5	2,2%
TOTAL	**765,97**	**100,0%**

Field survey was done to stablish SHPP installed base. There were found 105 SHPPs grouped in companies and installed capacity as shown in **Table 2**

Table 2. Colombian electric companies by installed capacity and number of SHPP (See ANNEX 1)

Company / Agent Operator	Capacity/ MW	Number of SHPPs
TOTAL	**719,57**	**105**
Aes Chivor & CIA. S.C.A. E.S.P.	19,7	1
CCG Energy S.A.S. E.S.P.	1,48	1
Celsia S.A E.S.P.	39,8	2
Cemex Energy S.A.S E.S.P.	7,25	2
Central Hidroeléctrica Concordia S.A.S. E.S.P.	5,7	1
Central Hidroeléctrica el Edén S.A.S. E.S.P.	20,6	
Centrales Eléctricas de Nariño S.A. E.S.P.	27,13	5
Compañía de Electricidad de Tuluá S.A. E.S.P.	14,17	3
Electrificadora Del Huila S.A. E.S.P.	11,14	3
Emgesa S.A. E.S.P.	110,91	10
Empresa de Energía de Pereira S.A. E.S.P.	8,5	2
Empresa De Energía Del Pacifico S.A. E.S.P.	72,57	6
Empresa Multipropósito De Calarcá S.A. E.S.P.	2	3
Empresa Municipal De Energía Eléctrica S.A E.S.P.	4,5	1
Empresas Públicas De Medellín S.A. E.S.P.	156,26	27
Enerco S.A. E.S.P.	7,55	3
Energética S.A. E.S.P.	1,2	1
Energía Del Rio Piedras S.A. E.S.P.	7,29	1
Energía Renovable De Colombia S.A. E.S.P.	2,28	1
Generadora Alejandría S.A.S. E.S.P.	15	1
Generadora Colombiana de Electricidad S.A. E.S.P.	0,38	1
Genercomercial S.A.S E.S.P	1,03	1
Generputumayo S.A.S. E.S.P.	0,94	2
HZ Energy S.A.S. E.S.P.	6,35	3
IAC Energy S.A.S. E.S.P.	4,8	1
Isagen S.A. E.S.P.	19,9	1
La Cascada S.A.S. E.S.P.	91	7
Risaralda Energía S.A.S. E.S.P.	19,9	1
Vatia S.A. E.S.P.	40,24	14

The expectations of the government are to go from a participation of NCRES in SIN from 3.5% to 6.5% (even in non-interconnected areas the expectation is to reach 30%) by 2020. This when the installed capacity in Colombia will be 18,000 MW, which will mean that there will be an increase from the current 765,97 MW to **1.423 MW** in NCRES. In summary, will needed an increase of **657 MW** in generation with NCRES, which is to double installed capacity on NCRES, where biggest potential is in SHPP. This is possible from the perspective of natural resources, since Colombia has the potential for hydro power generation (UPME, Pontificia Universidad Javeriana PUJ, Departamento Administrativo de Ciencia, Tecnología e Innovación COLCIENCIAS, Instituto de Hidrología, Meteorología y Estudios Ambientales IDEAM, 2015) and it has been classified by the International Renewable Energy Agency (IRENA), as the fourth country in the world with the highest potential of hydraulic generation (International Renewable Energy Agency IRENA, 2016) and the second in Latin America (see **Figure 2**). In total, per the National Energy Plan (PEN) (UPME, 2015), the potential of the SHPPs in Colombia was estimated at 25.000 MW, of which, according to an inventory of the National Non-Conventional

Energy Program, UPME, CORPOEMA, IRENA and the Universidad Nacional de Colombia (UPME, Pontificia Universidad Javeriana PUJ, Departamento Administrativo de Ciencia, Tecnología e Innovación COLCIENCIAS, Instituto de Hidrología, Meteorología y Estudios Ambientales IDEAM, 2015), (International Renewable Energy Agency IRENA, 2016) & (Flórez, 2006). To this potential, it must add that the price of MW/h with SHPPs in Colombia is below than the world average (Lozano & Rincón, 2010) (see **Figure 3**). With all the above, under a neutral scenario, it is estimated, that Colombia will duplicate the construction and the upgrading (Ortiz-Flórez, Chicango-Angulo, & Arias-Chasqui, 1996) of SHPP projects in the next decade.

Figure 2. Hydroelectric potential. Sources: (UPME, Pontificia Universidad Javeriana PUJ, Departamento Administrativo de Ciencia, Tecnología e Innovación COLCIENCIAS, Instituto de Hidrología, Meteorología y Estudios Ambientales IDEAM, 2015)(International Renewable Energy Agency IRENA, 2016)

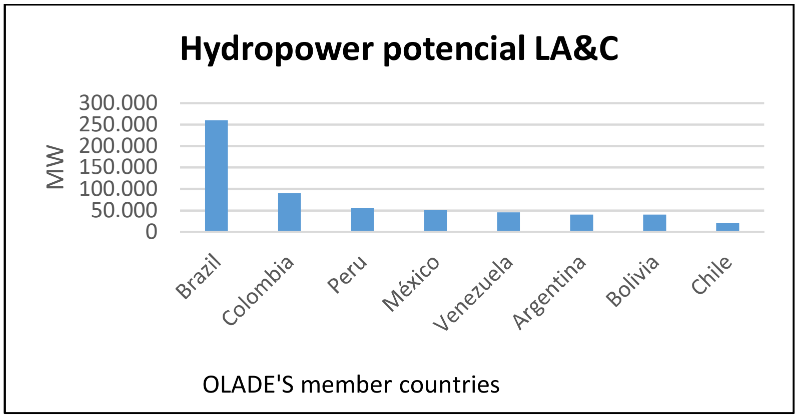
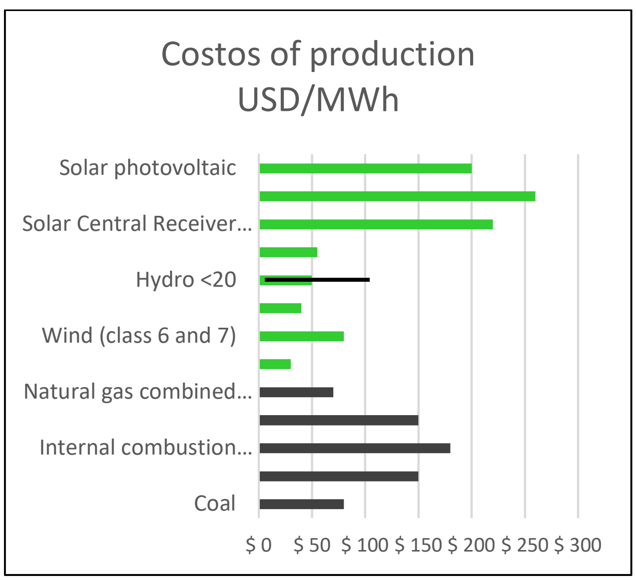


Figure 3. Renewable energy production costs. Source: (International Renewable Energy Agency IRENA, 2016)



In spite of having this great potential, in Colombia, only 3% it has been exploited in SHPP projects (Mining and Energy Planning Unit of Colombia; UPME, 2016c), (UPME, Pontificia Universidad Javeriana PUJ, Departamento Administrativo de Ciencia, Tecnología e Innovación COLCIENCIAS, Instituto de Hidrología, Meteorología y Estudios Ambientales IDEAM, 2015) & (International Renewable Energy Agency IRENA, 2016), due to several factors such as technical, market, economic, political, institutional, social and environmental barriers (Kim, Park, & Kim, 2017), (Morales, Álvarez, & Acevedo, 2015) & (Gallego, Franco, & Zapata, 2015). Given the complexity on the nature of the SHPP projects, given the number of variables and their non-linearity; The need for a management system that allows reducing the uncertainty in the achievement of the objectives and having a plan of action in different unforeseen scenarios or exceeding the desired values in said variables is appreciated.

In accordance with the classification given by renewable energy global experts (S.R. Bull, 2001)**,** cited law has established six types of renewable energy according to the manner in which they are obtained: biomass, from the sea, geothermal, wind and solar and SHPP. It is important to note that when preparing this article, the regulations in Law (LEY 1715, 2014) still has some pending matters by some state entities such as the Ministry of Mining and Energy, the Ministry of the Environment and the CREG [Spanish acronym for Energy and Gas Regulatory Commission]. Colombian Law (LEY 1715, 2014), indicates the tax and financial benefits for investment in NCRES projects that are following listed:

2.1 Income tax deduction as an incentive for research, development and investment in the context of production and use of energy through NCRES. The benefit consist in a "right to reduce from their income on a yearly basis for the next 5 years to the taxable year in which they have made the investment, fifty percent (50%) of the total amount of the investment made", with the condition: That the amount to be deducted does not exceed 50% of the taxpayer's liquid income determined before deducting the amount of the investment and that the environmental benefit of the investment has been certified by the Ministry of the Environment and Sustainable Development
2.2 Value Added Tax: Equipment, items, machinery and local or imported services that are destined to pre-investment and investment for the production and use of energy from non-conventional sources, as well as for the measurement and assessment of potential resources will be excluded from VAT. The benefit is conditioned to two circumstances: that the Mining and Energy Planning Unit [UPME - for its acronym in Spanish] issue a list of what equipment and services are used for the above-mentioned purpose and that the Ministry of the Environment and Sustainable Development certifies that equipment and services are excluded from VAT.
2.3 Exemptions from customs duties: This applies to the titleholders of new investments in new NCRES projects with respect to the importation of: machinery, equipment, materials and inputs. The requirements are a.) exclusive destination to pre-investment and investment activities in NCRES projects and b.) absence of local production and that its own means for acquisition is subject to the importation.
2.4 Accelerated depreciation: will be applicable to the machinery, equipment and civil works necessary for the pre-investment, investment and operation of the generation with NCRES that are acquired and/or built exclusively for this purpose, as of the entry in force of this law. For these purposes, the annual depreciation rate will not be greater than

> twenty percent (20%) as an annual global rate. The rate could vary on a yearly basis by the project titleholder, prior notice to the DIAN [National Tax and Customs Administration], without exceeding the limit established in this article, except in the cases in which the law authorizes greater global percentages.

With all the above-mentioned incentives, an increase in the amount of SHPP projects registered before UPME is expected. Therefore, a risk management system for NCRES projects is necessary. The intended methodological proposal seeks to serve as reference to define the resources to commence, execute and control a process for risk management in SHPP projects in Colombia. The description of this process ends with the development of a practical guide that in the future could be used to develop similar projects that are geared towards other non-conventional renewable energy technologies such as geothermal, wind, solar or biomass. Our specific objectives are: a) to identify the main risks presented in small hydroelectric power plant SHPP projects in Colombia; b) to assess the risks identified, qualify and quantify them for their treatment and c) to elaborate a methodology supported under the guidance of Colombian Technical Standard NTC5254 and NTC-ISO-31000-2011 (Icontec, 2004) & (Icontec, 2011), allows to manage the risks for SHPP projects in Colombia.

3. Methodology

According with (Hernández, Fernández, & Baptista, 2014), the approach of this research is quantitative, mainly because of data collection mode:

"The collection is based on standardized instruments. It is uniform for all cases. The data are obtained by observation, measurement and documentation. We use instruments that have proven to be valid and reliable in previous studies or are generated new based on the review of the literature and are tested and adjusted. The questions, items or indicators used are specific with answer possibilities or predetermined categories"

And because of data analysis:

"systematic and standardized, intensive use of statistics (descriptive and inferential), based on variables (a matrix), impersonal, done after data collection".

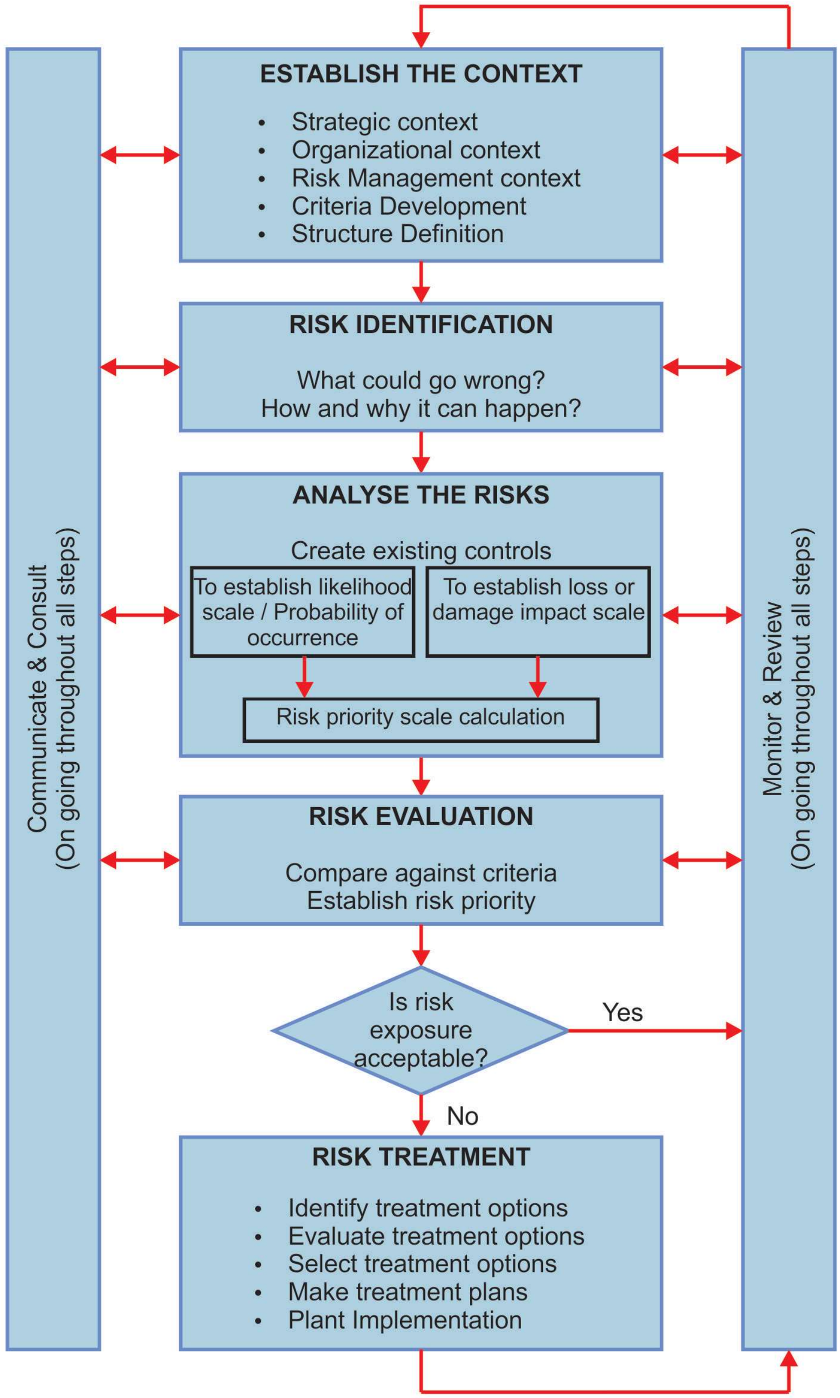
The methodology followed in this research is analytical, descriptive and transverse. A bibliographical review of the global literature was made in specialized scientific journals and databases. such review (See **Table 3**) shows that RM on renewable energy has been widely addressed in technical and financial issues and very focused in NCRES such as wind and solar. Any research in RM focused on SHPP was found. Elaborating a categorization of that by region, the outcome is: Europe (Klessmann, Nabe, & Burges, 2008) & (Kitzing, 2014), North America (Lee & Zhong, 2015). Latin America (Dyner, Arango, & Larsen, 2006) & (Guerrero-Liquet, Sánchez-Lozano, García-Cascales, Lamata, & Verdegay, 2016). In Colombia SHPP projects Colombia has traditionally focused in technical (Ortiz-Flórez, 2001) and financial issues (Sánchez, Lozano, & Manotas, 2014) & (Dagoumas, Koltsaklis, & Panapakidis, 2017). For all the above it is said that the relevance of this research is that any RM holistic approach for Small Hydro (SHPP) has never been done before in Colombia.

Table 3. Global Literature reviewed for State of art on Risk Management on Renewable Energy or SHPP

Titles that issue researches on renewable and Small Hydro SHPP
Energy Policy: The International Journal of the Political, Economic, Planning, Environmental and Social Aspects of Energy
Energy The: International Journal
Environment Magazine
Global Business and Management Research: An International Journal
Hydro Review
IEEE Latin America Transactions
IEEE Spectrum
Indian Journal of Power and River Vally Projects
International Conference on Small Hydro
International Journal of Water Power and Dam Construction
International Journal on Hydro
Irrigation and Power Journal
Journal of Cleaner Production
Renewable & Sustainable Energy Reviews
Renewable Energy an International Journal
Small Hydropower News
Sustainability — Open Access Journal

Expert judgment was done by applying the techniques recommended by Dorofee (Dorofee, Walker, & Alberts, 1996) and the Project Management Institute (PMI) (Project Management Institute, 2013). The barriers and risks involved in the development of SHPP projects were consulted, identified, classified and documented as variables. It was investigated how the SHPP projects are implemented, controlled and adapted during unplanned crises. The risk profile of the SHPPs sector in Colombia was typified and, finally, under the guidance of Colombian Technical Standards NTC5254 and NTC-ISO-31000-2011 (Icontec, 2004) & (Icontec, 2011), a methodological proposal to be used as a reference, that optimize the development of risk management in SHPP projects in Colombia, which includes: identification of the main risk variables; qualification; quantification; evaluation and response to these risk variables as shown in **Figure 4**.

Figure 4. Risk Management Process. Source (Icontec, 2004)



The identification of the risks was based on the characterization of the uncertainty that affects the objectives of the project, producing damages. For the development of this paper review, experts on projects of SHPPs from different companies involved on different phases of the projects in Colombia were consulted, as indicated in **Table 4**.

Table 4. SHPP Companies in Colombia where experts were consulted for this review

Power Generation Companies	Engineering and Construction Companies	Equipment Supply Companies
Celsia	AIA	Andritz
CHEC	Sedic	Hidroturbinas Delta
Emgesa	Gomez Cajiao	Nidec-Leroy Somer
Enerco	I-Consult	Voith
Epm	Ingetec	
Epsa	Integral	
Generadora union	Mincivil	
Generadora Alejandria	Rightside	
Genmas	Pi-epsilon	
Grupo Elemental		
HMV		
Isagen		
Latinco		
UT-Choc		

3.1 Identification and categorization of risks

To avoid bias and improve the identification of risk variables, with the help of experts, a list of events that cause adverse situations in the execution was elaborated. An organized categorization was gotten according to the following topics: Technical; Financial; commercial; Political, ethical and legal; Organizational; Environmental, and Community-related (Kim et al., 2017), (Morales et al., 2015), (Flórez, 2006), (Wüstenhagen, Wolsink, & Mary Jean Bürer, 2007), (Rosso-Cerón & Kafarov, 2015) & (Diez Hernández & Olmeda Sanz, 2013).

3.2 Qualification and determination of the severity of the risk using the matrix Impact-Probability of occurrence:

A RM that ensures the successful development of projects, must define the risk value. It was started by identifying if there is a threat or an opportunity, for this it is necessary to assign a probability of occurrence and an impact to the objectives of the project, (see **Table 5**).

Table 5. Risk priority scale: Probability / impact matrix

Likelihood or Probability of Occurrence								
	Very High (Certain)	10	Almost certain	Moderate	Important	**Intolerable**	**Intolerable**	**Intolerable**
	High (Almost Certain)	8	Tolerable	Tolerable	Moderate	Important	**Intolerable**	**Intolerable**
	Medium (Likely)	6	Tolerable	Tolerable	Tolerable	Moderate	Important	Important
	Slight (Possible)	4	Unlikely	Trivial	Trivial	Tolerable	Moderate	Important
	Low (Unlikely)	2	Rare	Trivial	Trivial	Trivial	Tolerable	Moderate
	Very Low (Rare)	1	Insignificant	Insignifica nt	Mild	Medium	Severe	**Catastrophic**
			1 Insignificant	2 Minor	4 Intermediate	6 Elevated	8 Severe	10 Catastrophic
	Impact							

3.3 Defined assessments for risk impact scales for the main project objectives:

For the evaluation and, to avoid limiting itself to the technical variables associated with the works and the equipment, it was decided to use a combination of Delphi technique and expert judgment (see **Table 6**).

Table 6. Matrix scales of impact in the risk

Type of risk	Relative or absolute scale (For negative impacts)					
Technical	Insignificant / .05	Slight/ .1	Medium / .2	High / .4	Severe / .6	Catastrophic / .8
Financial	Insignificant loss	< 10% loss	10 – 20% loss	20 – 30% loss	30 – 40% loss	> 40% loss
Political, ethical and legal	Decrease barely noticeable	Minimal affected areas	Major affected areas	It requires board of directors' approval	Unacceptabl e reduction for shareholders	Useless end result
Organizational	Decrease barely noticeable	Minimal affected areas	Major affected areas	It requires board of directors' approval	Unacceptabl e reduction for shareholders	Useless end result
Environmental	Degradation barely perceptible	Only specific parts of the project are impacted	Reduction requires Management approval	Reduction requires board of directors' approval	The unacceptable reduction for shareholders	Useless end result
Relationship with communities	Degradation barely perceptible	Only specific parts of the project are impacted	Reduction requires Management approval	Reduction requires board of directors' approval	The unacceptable reduction for shareholders	Useless end result
Impact	**Insignificant**	**Minor**	**Medium**	**Elevated**	**Severe**	**Catastrophic**

4. Results

Once the experts' judgment was consulted and organized on **Table 7**. The topics of risk were quantified. The parts of the process that are affected by these types of risk are identified during the SHPP project. It is explicitly explained what the risk consists in, if it becomes an event. Subsequently, the probability of occurrence and the impact that the event will have on the execution of the project is qualitatively assessed. Based on this weighting and per the percentage values of the risk impact scale matrix (**Table 6.**), the value of the risk is quantified where 100% is the maximum value.

*4.1 Categorization and weighting of risk variables for SHPP projects in Colombia are shown in **Table 7.***

Table 7. Risk Identification Matrix in SHP Projects

Type	Process or Work Activity	Risk	Proba-bility	Impact	Risk Value
Technical	Pre-feasibility and conceptual engineering	Excess of sensibility in the positive and negative scenarios that make the project unsustainable or dismiss qualitative elements.	Low	Severe	16% Tolerable
	Basic and detailed engineering	Not having detail engineering and go out to buy or bid with basic engineering. Changes in specifications or scopes	Slight	Severe	32% Moderate
	Civil works: Capture Gates, Driving, Equalization tank, Machinery room, Discharge	Changes in specifications or scopes Not provided work quantities Delivery times of suppliers different than the requested.	Slight	Severe	32% Moderate
	Electromechanical equipment: Inlet valve Turbine Generator Control and instrumentation system Substation Interconnection line to SIN	Changes in specifications or scopes Not provided work quantities Delivery times different than the requested Incompatibility between equipment from different manufacturers	Medium	Elevated	36% Moderate
	Generic Turbines and Generators Generic Vs Taylor made equipment	Less energy generated, due to decreased efficiency of the turbo-generator.	Medium	Severe	48% Important
	Interconnection Point	Increase in the cost of substation and electricity grid to deliver the generated energy, because of late definition of the interconnection point by the network operator	Medium	Catas-trophic	60% Important
Financial	Costs	Costs structure different than planned	High	Severe	64% Intolerable
	ROI	Changes in timing or in levels in which investors recover their investment	High	Severe	64% Intolerable
	Project's cash flow	Disbursement of resources different than planned Change in payment terms to suppliers	High	Severe	64% Intolerable

Type	Process or Work Activity	Risk	Proba-bility	Impact	Risk Value
	Exchange rates	Effects for drastic variation between currencies along project development. Difficulties in the linking of foreign capital resulting from the revaluation of the peso. High equipment imports costs due to the devaluation of the peso.	High	Interme-diate	32% Moderate
	Credits	Changes in the rating of the investment risk. Changes in interest rates. Changes in amounts or deadlines for disbursements of resources Breach of obligations	Medium	Interme-diate	24% Tolerable
	Taxes	Local or global taxes not contemplated in financial analysis	Medium	Interme-diate	24% Tolerable
	Parafiscal charges and fees	Additional operation and maintenance workforce. Extra non-wage labor costs that must be added. Further benefits to unions	Medium	Catas-trophic	60% Important
Commer-cial	Sale Fees	Different fees to those contemplated in the financial analysis	Medium	Catas-trophic	60% Important
	Global and local market	Variations in commodity prices (Eg. Steel) that affect the cost of the investment. Variations in supply-demand of energy.	Baja	Minor	4% Trivial
	Entry into operation of other projects	Because of the entry into operation of new generation projects and increase in the available basket, decrease in the sale price of power	High	Interme-diate	32% Moderate
	Clients	Changes in the objective energy consumer requirements	Low	Minor	8% Trivial
	Competitors	Price war.	Low	Insigni-ficant	2% Rare
Political, Ethical and Legal	Licenses	Delays not contemplated in obtaining licenses Requirement of Licenses not contemplated in feasibility studies	High	Interme-diate	32% Moderate
	Concessionaires	Elements not expressly considered in the concession agreement.	Slight	Severe	32% Moderate
	Employment agreements	Elements not expressly considered in the direct employment agreements or subcontractors	Slight	Interme-diate	8% Trivial
	Sale of energy agreements	Lack of sale of energy agreements Changes in the elements of the same	Leve	Catastro-phic	64% Intolerable
	Agreements with suppliers	Changes in quotes and purchase orders or agreements with suppliers	High	Minor	16% Tolerable
	Agreements with subcontractors	Differences between the specifications requested or terms requested and those delivered	High	Minor	16% Tolerable
	Legal and legislative security	Changes in the law under which the project was evaluated. Legal or political elements of government not contemplated in the studies Changes in government	Medium	Severe	48% Important

Type	Process or Work Activity	Risk	Proba-bility	Impact	Risk Value
	Presencia de especuladores para aprovechar el recurso hídrico	Presencia de trámites ambientales y ante la UPME de proyectos de hidroenergía que estén en manos de personas que sólo quieren negociar con ellos.	Medium	Severe	48% Importante
Organi-zational	Poor planning process	Weak plants or lack of follow-up of planning	High	Minor	16% Tolerable
Organi-zational	Leadership	Changes in leadership or strategic personnel of the work team. Work environment elements in the project team	High	Insignifi-cant	16% Tolerable
Organi-zational	Occupational health and safety management system	Work accidents. Deadlines are affected because of detection of anomalies in the audits	Medium	Interme-diate	24% Tolerable
Organi-zational	Control and management documentation	Lack of policies, resources or an adequate C&D process	Medium	Minor	24% Tolerable
Environ-mental	Hydrology	River flow and/or its tributary levels different from those projected. Low levels of rainfall in the project's area of influence. Elements that modify turbidity or solid levels in suspension.	Low	Severe	32% Moderate
Environ-mental	Ambiental license	Times exceeded in the procedures required for environmental licensing to governmental entities, such as: Evaluation of the AAD UPME concept Evaluation of EIA Approval of the archaeological plan by ICANH.	High	Intermi-diate	32% Moderate
Environ-mental	Environmental regulatory changes	Changes in the competencies of the environmental authorities for the evaluation of the project. New conditions, procedures, fees and taxes for the licensing of the project.	Medium	Severe	48% Important
Environ-mental	Earthquakes	Telluric movements of higher levels than those contemplated in the studies	Medium	Leve	12% Tolerable
Environ-mental	Landslides	Earth movements or debris in places or at magnitudes not contemplated	Medium	Leve	12% Tolerable
Environ-mental	Avalanches	Changes in the river bed because of land movements, debris or rocks in the course of the river and/or its tributaries	Medium	Medio	24% Tolerable
Relation-ship with the commu-nities	Situation of the community	Area of influence different from the one defined in the studies. Social elements not contemplated in the area of influence	High	Interme-diate	32% Moderate
Relation-ship with the commu-nities	Social cartography and mapping	Deficient or non-existent survey of the social dimension in the areas of direct and indirect influence (ADI & AII).	High	Interme-diate	32% Moderate
Relation-ship with the commu-nities	Communication and public image	Lack of measurement or defects in the levels of perception of the community in the area of influence (ADI & AII).	Media	Leve	12% Tolerable

Type	Process or Work Activity	Risk	Proba-bility	Impact	Risk Value
		Lack of communication plans or defects in the same. Information leaks			
	Project socialization	Defects or nonexistence of a plan for the relationship with the community. Lack of socialization of relevant parts of Risk Management plan to the community in the area of influence (ADI & AII). Changes in the social elements considered in the plan	Media	Leve	12% Tolerable

4.2 Management of risk variables, response and action plans:

There are different ways of approaching the actions to be taken against the risks that arise in the development of a project, as listed below:

4.2.1 Avoiding the risk: not to continue with the risky activity (Not always possible)
4.2.2 Transferring the risk: that another party assumes part of the risk (To think which new risks cause this change)
4.2.3 Reducing the risk: take measures tending to reduce the probability of occurrence and/or impact, (Does not always imply additional financial costs, It can even save money)
4.2.4 Accepting the risk: accept the inherent risk (But with knowledge)

4.3 Results Analysis and Discussion

In accordance with the mathematical approach of the Markowitz model (Das, Markowitz, Scheid, & Statman, 2010), the behavior of a project manager who is responsible for maintaining the levels of return of the project is characterized by the degree of the risk aversion to the risk it has and the degree of maximization of the expected profit. There are three positions towards risk, summarized on the **Table 8**:

The results Risk profile of the sector in Colombia by consulted expert's valuation is that the total average risk value of all risk variables is **31.3%** (Neutral)**.** The value of each of the categories is: technical 37% (Averse), financial 42% (Averse), commercial 21% (Prone), political-ethical-legal 33% (Averse), organizational 20% (Neutral), environmental 22% (Neutral), relationship with communities 16% (Prone).

Table 8. Risk profile. Source: (Das et al., 2010)

Risk aversion	It refers to when the investor would choose an investment with the lowest degree of risk versus two alternatives with the same level of expected profitability.
Risk Neutrals	In this situation, the investor would remain indifferent if he had to choose between two alternatives with the same level of expected profitability.
Prone to Risk	The investor would choose the investment with the highest degree of risk against two alternatives with the same level of expected profitability.

For the present paper review, and per the consensus of the consulted experts, which is the standard of engineering in Colombia (Noguera, 2017) & (Icontec, 2011), the risk management response and action plans for each type of risk, is explained in **Table 9.**

Table 9. Proposal of risk response.

Type of risk	Risk response
Technical	Design and implementation of both: a policy and a contingency plan that makes it possible to reduce to the minimal the possibility of: **a)** producing a generated power with an efficiency different from the required. **b)** Incorrectly assume issues related to the connection point by the network operator. **c)** overpass budgets by assuming: amounts of work, prices or terms.
Financial and Commercial	Increase knowledge of financial variables and minimize uncertainty. Reduce risk by monthly monitoring of all variables. Use Monte Carlo simulations or Artificial Neural Network (ANN) to make quantitative assessments of levels of exposure to financial risks
Political, ethical and legal	Ensure full knowledge of the conditions agreed in the contract, to determine the positive or negative impact on the project balance of regulatory changes. Establish Training programs for all staff at all organizational levels in a culture of zero tolerance to compliance and ethical issues.
Organizational	Be prepared by succession plans, to assume the changes of strategic personnel and leadership style that are usual in the projects of SHPPs.
Environmental	To transfer the risk through the contracting of environmental consultancies that are responsible for the achievement of environmental permits, projection of documents and material management thereof, monitoring possible changes in environmental policies and legislation and the execution of environmental plan and obligations.
Relationship with communities	Accompany the socialization of the project with the study of social cartography and mapping. Define the Areas of Direct Influence (ADI) and the Area of Indirect Influence (AII). Increase the channels of communication to get more in touch with the communities .

This methodology to be used as guideline should be completed case by case, by using the proposed template for risk treatment plan included in the **Annex 2.** In column 4 of such Annex are suggested some risk responses that might be used and complemented with what are suggested in **Table 9.**

5. Conclusions and recommendations

Adequate risk management will provide high chances of increasing the perdurability of the organizations involved in SHPP projects. Risk management helps to achieve the main objectives of these organizations, to improve their self-knowledge, to improve productivity and ensure efficiency and effectiveness at productive processes. It will allow defining strategies for continuous improvement and definition of actions to be taken in the face of unexpected events or situations in which there is high uncertainty.

For technical risks, it is important to bear in mind that because of economies of scale (EOS) (Arias-Gaviria, van der Zwaan, Kober, & Arango Aramburo, 2017)**,** (Morales et al., 2015), the use of turbines and generators manufactured in series for different flows and heights is increasing. These solutions are usually cheaper than those implemented with equipment tailored to the particular characteristics of the project. The efficiency of power generated and delivered power must be considered. Likewise, in Colombia it should be considered at an early stage the connection point by the network operator. It can cause high costs to get a distribution network to deliver the generated power. Most of the experts consider this as a concern.

For financial risks, it is recommended to use techniques and models such as Monte Carlo simulations (Arnold & Yildiz, 2015) or Artificial Neural Network (ANN) to make quantitative assessments of levels of exposure to financial risks (Sánchez et al., 2014), (Dagoumas et al., 2017)**.** This is to increase knowledge of all variables and minimize uncertainty. It is frequent in Colombia that from the feasibility and financial closure stages until the implementation of the project, can take one or two years, even when stakeholders try to manage financial risk through public-private partnerships. Therefore, an update of the study of financial risk variables at the time of project start is advised. For example, the minimum selling price of energy is a fundamental calculation that determines the zero point, that is, the selling price where it is not lost or profit value with the operation of the SHPP and that can easily change during two years for elements such as: demand, fees, service, rights, non-payment, credit evasion; which lead to a lower cash flow than expected.

Most experts agree on that for organizational and leadership issues, programs and processes, must exist and function independently of people; changes of leaders and strategic personnel are common in SHPP projects. Depending on the stage of the project, the leader and leadership style required may change. In the SHPPs sector, project planning must be strengthened to operate successfully regardless of the type of leadership. It is precisely for this reason that a methodology for risk management adds value in the way in which SHPP projects are developed in Colombia.

Although both the electricity sector and the Colombian market are highly regulated, in the Wholesale Energy Market, SHPPs (no dam) are always dispatched, a monthly update of the financial risk variables is necessary, whenever market conditions change substantially. For example, the case of the near entrance of the hydroelectric plant Ituango (2,456MW), without even entering to operate, already caused that they did not make auctions for reliability in the 2016.

Consultations prior to the communities are of great importance for the development of energy infrastructure projects and particularly for SHPP projects not only in Colombia but throughout all the world (Wüstenhagen et al., 2007). Although the socialization of the project is an obligation for licensing, social cartography and mapping is not usually evaluated, which is a serious error. This does not allow to know to the investors of the project, the initial social conditions of the zone of the project. Therefore, management does not have social baseline. This common mistake brings many problems when conducting land rights and fees negotiation, which defines community compensation and relocation activities. Social cartography and mapping allows the project manager to have a baseline and a detailed diagnosis of the social composition of the Area of Direct Influence (**ADI**) and Area of Indirect Influence (**AII**), which mitigates the risk of population increase at the time of implementing the project. It is common for many people to move to areas where projects will be built to try to get compensated. It is the social cartography in the ADIs and the AIIs for power generation projects in Colombia an issue that most experts found as a point of interest for future research studies. Increasing the channels of communication to get more in touch with the communities is also big concern between the experts.

The opinion of many of the specialists consulted agree that the enormous dynamics in environmental issues and the lack of legal security in Colombia have caused the non-viability of projects of SHPPs, which is why foreign investors are advised by local consultancy firms who have experience in handling environmental legislation issues and even in relationship to communities. The impact on the public image of the organization that develops the SHPP projects is slight, if it is a standalone project (isolated), but when it is a project developed by an economic group or a large company in the market, the impact is medium or becomes severe, this because the blow in the indicators of reputation and brand positioning. In the latter case, it is highly recommended that the communications plan be also handled by local specialists.

This work is the spearhead of research in NCRES for line of research in Environment and International Business of the Masters in Management of the Universidad del Rosario. Future researches on risk management for projects that use other sources of energy in Colombia such as photovoltaic, wind and geothermal is a new field of study. On the same way, looking for case studies that evaluate this and oncoming methodologies will be useful for community, academy and renewable power industry.

Under the guidance of Colombian Technical Standard (Icontec, 2011), a methodological proposal has been developed for risk management in SHPP projects in Colombia, which includes: identification of the main risk variables; qualification; quantification; evaluation and response to these risk variables. A methodological reference for risk management that improves the development of SHPP projects, has been provided.

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7. References

Arias-Gaviria, J., van der Zwaan, B., Kober, T., & Arango Aramburo, S. (2017). The prospects for Small Hydropower in Colombia. *Renewable Energy*. https://doi.org/10.1016/j.renene.2017.01.054

Arnold, U., & Yildiz, O. (2015). Economic risk analysis of decentralized renewable energy infrastructures - A Monte Carlo Simulation approach. *Renewable Energy*, *77*(1), 227–239. https://doi.org/10.1016/j.renene.2014.11.059

Cai, W., & Borlace, S. (2014). Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature Climate Change*, *4*(2), 111–116.

Collins, M., An, S.-I., & Cai, W. (2010). The impact of global warming on the tropical Pacific Ocean and El Nino. *Nature Geosci*, *3*(6), 391–397.

Consorcio Energético CORPOEMA. (2010). Plan de Desarrollo para las Fuentes no Convencionales de Energía en Colombia (PDFNCE). *Formulación de Un Plan de Desarrollo Para Las Fuentes No Convencionales En Colombia (PDFNCE) V1*, *1*, 25–28.

Dagoumas, A. S., Koltsaklis, N. E., & Panapakidis, I. P. (2017). An integrated model for risk management in electricity trade. *Energy*, *124*, 350–363. https://doi.org/10.1016/j.energy.2017.02.064

Das, S., Markowitz, H., Scheid, J., & Statman, M. (2010). Portfolio Optimization with Mental Accounts. *Journal of Financial and Quantitative Analysis*, *45*(2), 311–334. https://doi.org/10.1017/S0022109010000141

Departamento Nacional De Planeación (DNP). (2017). Bases del Plan Nacional de Desarrollo 2014-2018, 861. Retrieved from https://colaboracion.dnp.gov.co/cdt/prensa/bases plan nacional de desarrollo 2014-2018.pdf

Diez Hernández, J. M., & Olmeda Sanz, S. (2013). DISEÑO ECO-HIDROLÓGICO DE PEQUEÑAS CENTRALES HIDROELÉCTRICAS: EVALUACIÓN DE CAUDALES ECOLÓGICOS. *Revista Energética Número39 , Julio de 2008 - ISSN 0120-9833*, 662–666. https://doi.org/ISSN

Dorofee, A. J., Walker, J. a, & Alberts, C. J. (1996). *Risk Management Guidebook*.

Dyner, I., Arango, S., & Larsen, E. R. (2006). Understanding the Argentinean and Colombian Electricity Markets. *Electricity Market Reform*, (1993), 595–616. https://doi.org/10.1016/B978-008045030-8/50019-9

Flórez, R. O. (2006). Método para la evaluación de los recursos hidroenergéticos en pequeña escala. *Revista Energía Y Computación Vol. 15 No. 1 Junio de 2007 P. 15 - 20*, *15*(1), 15–20.

Gallego, J. D., Franco, C. J., & Zapata, S. (2015). Policies for the utilization of hydropower potential in Colombia using small plants. *IEEE Latin America Transactions*, *13*(12), 3844–3850. https://doi.org/10.1109/TLA.2015.7404918

García Arbeláez, C., Barrera, X., Gómez, R., & Suárez Castaño, R. (2015). *El ABC de los compromisos de Colombia para la Cop 21*. *Flora*.

Gualteros, M. V., & Hurtado, E. (2013). REVISIÓN DE LAS REGULACIONES E INCENTIVOS PARA EL USO DE LAS ENERGÍAS RENOVABLES EN COLOMBIA. *JURÍDICAS. No. 1, Vol. 10, Pp. 209-224. Manizales: Universidad de Caldas*, *10*, 209–224.

Guerrero-Liquet, G. C., Sánchez-Lozano, J. M., García-Cascales, M. S., Lamata, M. T., & Verdegay, J. L. (2016). Decision-making for risk management in sustainable renewable energy facilities: A case study in the Dominican Republic. *Sustainability (Switzerland)*, *8*(5). https://doi.org/10.3390/su8050455

Hernández, R., Fernández, C., & Baptista, P. (2014). *Metodología de la investigación*. *Journal of Chemical Information and Modeling* (6th ed., Vol. 53). Mc. Graw Hill.

Hoyos, N., Escobar, J., Restrepo, J. C., Arango, A. M., & Ortiz, J. C. (2013). Impact of the 2010-2011 La Niña phenomenon in Colombia, South America: The human toll of an extreme weather event. *Applied Geography*, *39*(September 2011), 16–25. https://doi.org/10.1016/j.apgeog.2012.11.018

Icontec. (2004). Norma Técnica Colombiana para 5254 la Gestión de Riesgos., 44.

Icontec. (2011). Gestión del riesgo principios y directrices NTC-ISO 31000, (571), 1–12.

International Renewable Energy Agency IRENA. (2016). *Renewable Energy Market Analysis: Latin America*. *Irena*. https://doi.org/http://www.irena.org/DocumentDownloads/Publications/IRENA_Market_GCC_2016.pdf

Kates, R. W., Parris, T. M., & Leiserowitz, A. A. (2016). What is sustainable development? *Environment*, *47*(3), 8.

Kim, K., Park, H., & Kim, H. (2017). Real options analysis for renewable energy investment decisions in developing countries. *Renewable and Sustainable Energy Reviews*, *75*(October 2015), 918–926. https://doi.org/10.1016/j.rser.2016.11.073

Kitzing, L. (2014). Risk implications of renewable support instruments: Comparative analysis of feed-in tariffs and premiums using a mean-variance approach. *Energy*, *64*, 495–505. https://doi.org/10.1016/j.energy.2013.10.008

Klessmann, C., Nabe, C., & Burges, K. (2008). Pros and cons of exposing renewables to electricity market risks-A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy*, *36*(10), 3646–3661. https://doi.org/10.1016/j.enpol.2008.06.022

Lai, F., & Shad, M. (2017). Economic Value Added Analysis for Enterprise Risk Management. *Global Business and Management*, *9*(July), 338–348.

Lee, C. W., & Zhong, J. (2015). Financing and risk management of renewable energy projects with a hybrid bond. *Renewable Energy*, *75*, 779–787. https://doi.org/10.1016/j.renene.2014.10.052

Ley 1715. (2014). Diario oficial. *DIARIO OFICIAL República de Colombia*, (Año CL No. 49.150). Retrieved from http://www.upme.gov.co/Normatividad/Nacional/2014/LEY_1715_2014.pdf

Lozano, I., & Rincón, H. (2010). Formación de las Tarifas Eléctricas e Inflación en Colombia. *Banco de La República*, 21–23. Retrieved from http://www.banrep.gov.co/sites/default/files/publicaciones/pdfs/borra634.pdf

Mining and Energy Planning Unit of Colombia; UPME. (2006). *Balances Energéticos 1975 - 2006*. Retrieved from http://www.upme.gov.co/Docs/balance_energetico_2006.pdf

Mining and Energy Planning Unit of Colombia; UPME. (2016a). Indicative Plan of Natural Gas Supply, 109.

Mining and Energy Planning Unit of Colombia; UPME. (2016b). Plan De Acción Indicativo De Eficiencia Energética 2016 - 2021.

Mining and Energy Planning Unit of Colombia; UPME. (2016c). Proyección de Demanda de Energía Eléctrica y Potencia Máxima en Colombia, 55. Retrieved from http://www.siel.gov.co/siel/documentos/documentacion/Demanda/UPME_Proyeccion_Demanda_Energia_Electrica_Junio_2016.pdf

Morales, S., Álvarez, C., & Acevedo, C. (2015). An overview of small hydropower plants in Colombia: Status, potential, barriers and perspectives. *Renewable and Sustainable Energy Reviews*, *50*, 1650–1657. https://doi.org/10.1016/j.rser.2015.06.026

Noguera, G. (2017). Alternativas de Gestión de Riesgos en la Empresa. *Asociación Colombiana de Ingeniero ACIEM, 128*, 76.

Ortiz-Flórez, R. (2001). *Pequeñas Centrales Hidroeléctricas*. (M. G. Hill., Ed.). Mc. Graw Hill.

Ortiz-Flórez, R., Chicango-Angulo, H., & Arias-Chasqui, A. (1996). Modernizacion de la Planta Rio Cali. *Energía Y Computación, V*(11).

Pardo Martínez, C. I., & Alfonso Piña, W. H. (2015). Regional analysis across Colombian departments: A non-parametric study of energy use. *Journal of Cleaner Production*, *115*, 130–138. https://doi.org/10.1016/j.jclepro.2015.12.019

Pope Francis. (2015). Laudato si: On care for our common home. *Our Sunday Visitor.*

Project Management Institute. (2013). *Guía de los fundamentos para la dirección de proyectos*. *Global Standard* (Vol. 87).

Renewable Energy Policy Network for the 21st Century REN21. (2016). *Renewables 2016 Global Status Report*. https://doi.org/ISBN 978-3-9818107-0-7

Rosso-Cerón, A. M., & Kafarov, V. (2015). Barriers to social acceptance of renewable energy systems in Colombia. *Current Opinion in Chemical Engineering*, *10*, 103–110. https://doi.org/10.1016/j.coche.2015.08.003

S.R. Bull. (2001). Renewable energy today and tomorrow. *Proceedings of the IEEE*, (0), 89(8), 1216-1226.

Sánchez, M., Lozano, C. A., & Manotas, D. (2014). Modelo de valoración de riesgo financiero en la gestión de contratos de suministro de energía eléctrica. *Tecnura*, *18*(39), 110–127. https://doi.org/10.14483/udistrital.jour.tecnura.2014.1.a08

UPME. (2015). Plan Energetico Nacional Colombia: Ideario Energético 2050. *Mining and Energy Planning Unit of Colombia; UPME*, 184. Retrieved from http://www.upme.gov.co/Docs/PEN/PEN_IdearioEnergetico2050.pdf

UPME, Pontificia Universidad Javeriana PUJ, Departamento Administrativo de Ciencia, Tecnología e Innovación COLCIENCIAS, Instituto de Hidrología, Meteorología y Estudios Ambientales IDEAM, I. G. A. C. I. (2015). Atlas del Potencial Hidorenergético De Colombia.

Wüstenhagen, R., Wolsink, M., & Mary Jean Bürer. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, *35*(5), 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001

ANNEX 1. SHPP Colombian installed base by capacity, number of SHPP, ubication and date of startup. Source: Own construction from XM data

Agent Operator/Central	Capacity/ MW	Number of SHPPs	State (Dept.)	County	Date of startup
Total	719,57	105			
EMPRESAS PUBLICAS DE MEDELLÍN S.A. E.S.P.	**156,26**	**27**			
AMERICA	0,41		Antioquia	Medellín	1/01/1997
CAMPESTRE (EPM)	0,87		Antioquia	Medellín	1/01/1997
PIEDRAS BLANCAS	5		Antioquia	Medellín	1/01/1900
NUTIBARA	0,75		Antioquia	Medellín	1/01/1997
AMALFI	0,81		Antioquia	Amalfi	5/08/2007
PORCE III MENOR	1,8		Antioquia	Amalfi	25/04/2016
BELLO	0,35		Antioquia	Bello	1/01/1997
MANANTIALES	3,15		Antioquia	Bello	1/01/1992
NIQUIA	19		Antioquia	Bello	28/06/1993
LA VUELTA	11,6		Antioquia	Canasgordas	22/11/2004
CARACOLÍ	2,6		Antioquia	Caracolí	1/01/1935
RIOGRANDE I	19		Antioquia	Don Matías	1/01/1956
RIO GRANDE	0,3		Antioquia	Don Matías	1/12/2007
AYURA	18		Antioquia	Envigado	26/10/1983
CEMENTOS DEL NARE	4,5		Antioquia	Pto Nare	1/09/2004
SAN JOSE DE LA MONTAÑA	0,4		Antioquia	S. Josela Monta	30/07/2007
RIO ABAJO	0,9		Antioquia	San Vicente	1/01/1947
SONSÓN	18,5		Antioquia	Sonsón	1/06/2002
RIOFRIO (TAMESIS)	1,2		Antioquia	Tamesis	1/01/1951
PAJARITO	4,9		Antioquia	Yarumal	25/11/1999
INTERMEDIA	0,96		Caldas	Manizales	1/01/1974
SAN CANCIO	2		Caldas	Manizales	1/01/1929
MUNICIPAL	1,4		Caldas	Manizales	1/01/1935
INSULA	19		Caldas	Chinchiná	20/07/1995
GUACAICA	0,86		Caldas	Neira	1/01/1992
CASCADA	3		Santander	Bucaramang a	1/01/1954
PALMAS SAN GIL	15		Santander	San Gil	1/01/1954
VATIA S.A. E.S.P.	**40,24**	**14**			
SANTIAGO	2,8		Antioquia	Santo Domingo	8/01/2011
FLORIDA	19,9		Cauca	Popayan	1/01/1975
OVEJAS	0,82		Cauca	Buenos Aires	1/01/1939
RIO PALO	1,44		Cauca	Caloto	1/01/1960
INZA	0,75		Cauca	Inza	5/02/2009
SAJANDI	3,2		Cauca	Patia (El Bordo)	1/01/1995

Agent Operator/Central	Capacity/ MW	Number of SHPPs	State (Dept.)	County	Date of startup
MONDOMO	0,75		Cauca	Santander De Quilichao	1/01/1958
SILVIA	0,38		Cauca	Silvia	1/01/1994
ASNAZU	0,45		Cauca	Suarez	1/01/1934
MIROLINDO	3,75		Tolima	Ibagué	3/11/2004
VENTANA A	2,5		Tolima	Chicoral	1/11/1957
VENTANA B	2,5		Tolima	Chicoral	1/11/1957
RIO RECIO	0,3		Tolima	Lérida	1/11/1958
PASTALES	0,7		Tolima	Pastales	18/02/2004
EMGESA S.A. E.S.P.	**110,91**	**10**			
CANTAYUS	4,32		Antioquia	Cisneros	4/05/2017
SUBA	2,55		Bogotá D.E.	Suba	15/04/2013
USAQUEN	1,74		Bogotá D.E.	Usaquén	15/04/2013
RIONEGRO	9,6		Cundinamarca	Puerto Salgar	1/01/1975
EL LIMONAR	18		Cundinamarca	San Antonio de Tena	6/12/2003
TEQUENDAMA	19,4		Cundinamarca	San Antonio de Tena	10/04/2004
LAGUNETA	18		Cundinamarca	San Antonio de Tena	17/12/2014
CHARQUITO	19,4		Cundinamarca	Soacha	22/08/2003
SANTA ANA	8		Cundinamarca	Ubalá	9/06/2005
GUAVIO MENOR	9,9		Cundinamarca	Ubalá	27/04/2016
LA CASCADA S.A.S. E.S.P.	**91**	**7**			
EL POPAL	19,9		Antioquia	Cocorna	31/03/2014
EL MOLINO	19,9		Antioquia	Cocorna	1/04/2017
SAN MATÍAS	10		Antioquia	Cocorna	17/03/2017
BARROSO	19,9		Antioquia	Salgar	30/11/2012
LA CASCADA (ANTIOQUIA)	2,3		Antioquia	San Roque	17/07/2007
CARUQUIA	9,5		Antioquia	Santa Rosa de Osos	28/01/2010
GUANAQUITAS	9,5		Antioquia	Santa Rosa de Osos	30/06/2010
EMPRESA DE ENERGIA DEL PACIFICO S.A. E.S.P.	**72,57**	**6**			
PRADO IV	5		Tolima	Prado	1/03/1973
NIMA	6,7		Valle del Cauca	Cali	1/01/1942
RIO CALI	1,8		Valle del Cauca	Cali	1/01/1925
AMAIME	19,17		Valle del Cauca	Palmira	6/01/2011
ALTO TULUA	19,9		Valle del Cauca	Tuluá	28/05/2012
BAJO TULUA	20		Valle del Cauca	Tuluá	30/01/2015
CENTRALES ELECTRICAS DE NARIÑO S.A. E.S.P.	**27,13**	**5**			
RIO BOBO	4		Cauca	Santa Rosa	1/01/1960
JULIO BRAVO	1,5		Nariño	Pasto	1/01/1942

Agent Operator/Central	Capacity/ MW	Number of SHPPs	State (Dept.)	County	Date of startup
RIO MAYO	19,8		Nariño	San Pablo	20/07/1995
RIO INGENIO	0,18		Nariño	Sandona	1/01/1958
RIO SAPUYES	1,65		Nariño	Tuquerres	1/01/1954
COMPANIA DE ELECTRICIDAD DE TULUA S.A. E.S.P.	**14,17**	**3**			
RIO FRIO II	10		Valle del Cauca	Riofrio	1/01/1996
RIO FRIO I	1,67		Valle del Cauca	Riofrio	1/01/1954
RUMOR	2,5		Valle del Cauca	Tulua	1/01/1999
ELECTRIFICADORA DEL HUILA S.A. E.S.P.	**11,14**	**3**			
LA PITA	1,42		Huila	Garzon	1/01/1965
IQUIRA I	4,32		Huila	Iquira	1/01/1955
IQUIRA II	5,4		Huila	Iquira	1/01/1965
EMPRESA MULTIPROPOSITO DE CALARCA S.A. E.S.P.	**2**	**3**			
BAYONA	0,6		Quindío	Bohemia	1/01/1943
CAMPESTRE (CALARCA)	0,7		Quindío	Bohemia	1/01/1956
UNION	0,7		Quindío	Bohemia	1/01/1935
ENERCO S.A. E.S.P.	**7,55**	**3**			
LA CASCADA (ABEJORRAL)	3		Antioquia	Abejorral	17/09/2007
SANTA RITA	1,3		Antioquia	Andes	18/08/2010
PUENTE GUILLERMO	1		Santander	Puente Nacional	1/09/2001
HZ ENERGY S.A.S. E.S.P.	**6,35**	**3**			
PROVIDENCIA	4,9		Antioquia	Anori	30/09/2015
REMEDIOS	0,75		Antioquia	Remedios	19/09/2007
LA REBUSCA	0,7		Antioquia	San Roque	24/07/2014
CELSIA S.A E.S.P.	**39,8**	**2**			
HIDROMONTAÑITAS	19,9		Antioquia	Don Matías	14/06/2012
RIO PIEDRAS	19,9		Antioquia	Jerico	31/03/2000
CEMEX ENERGY S.A.S E.S.P.	**7,25**	**2**			
SUEVA 2	6		Cundinamarca	Junin	24/05/2002
CURRUCUCUES	1,25		Tolima	Rovira	18/08/2010
CENTRAL HIDROELÉCTRICA EL EDÉN S.A.S. E.S.P.	**20,6**	**2**			
EL EDÉN	19,9	2	Caldas	Marquetalia	2/03/2017
EL COCUYO	0,7		Valle del Cauca	Versalles	20/05/2016
EMPRESA DE ENERGIA **DE PEREIRA S.A. E.S.P.**	**8,5**	**2**			
BELMONTE	3,4		Risaralda	Pereira	1/01/1939
NUEVO LIBARE	5,1		Risaralda	Dos Quebradas	1/01/1994
AES CHIVOR **& CIA. S.C.A. E.S.P.**	**19,7**	**1**			
TUNJITA	19,7		Boyacá	Tunja	30/06/2016
CCG ENERGY **S.A.S. E.S.P.**	**1,48**	**1**			
PATICO - LA CABRERA	1,48		Cauca	Popayan	1/01/1930
CENTRAL HIDROELÉCTRICA **CONCORDIA S.A.S. E.S.P.**	**5,7**	**1**			

Agent Operator/Central	**Capacity/ MW**	**Number of SHPPs**	**State (Dept.)**	**County**	**Date of startup**
MAGALLO	5,7		Antioquia	Concordia	22/12/2016
EMPRESA **MUNICIPAL DE ENERGIA ELECTRICA S.A E.S.P.**	**4,5**	**1**			
COCONUCO	4,5		Cauca	Popayan	27/09/2000
ENERGETICA **S.A. E.S.P.**	**1,2**	**1**			
COELLO	1,2		Tolima	Coello	10/12/2016
ENERGIA DEL RIO PIEDRAS **S.A. E.S.P**	**7,29**	**1**			
AGUA FRESCA	7,29		Antioquia	Jericó	1/01/2005
ENERGIA RENOVABLE DE COLOMBIA S.A. E.S.P.	**2,28**	**1**			
EL BOSQUE	2,28		Quindío	Armenia	1/01/1935
GENERADORA ALEJANDRIA S.A.S. E.S.P.	**15**	**1**			
ALEJANDRÍA	15		Antioquia	Alejandría	30/09/2016
GENERADORA COLOMBIANA DE ELECTRICIDAD S.A. E.S.P.	**0,38**	**1**			
SAN JOSE	0,38		Caldas	Pensilvania	16/11/2003
GENERCOMERCIAL S.A.S E.S.P.	**1,03**	**1**			
URRAO	1,03		Antioquia	Urrao	30/07/2007
GENERPUTUMAYO S.A.S. E.S.P.	**0,94**	**2**			
LA FRISOLERA	0,47		Caldas	Salamina	29/04/2016
SAN FRANCISCO (PUTUMAYO)	0,468		Putumayo	San Francisco	15/12/2012
IAC ENERGY S.A.S. E.S.P.	**4,8**	**1**			
LA NAVETA	4,8		Cundinam arca	Apulo (R.reyes)	27/11/2014
ISAGEN S.A. E.S.P.	**19,9**	**1**			
CALDERAS	19,9		Antioquia	San Carlos	12/07/1996
RISARALDA ENERGIA S.A.S. E.S.P.	**19,9**	**1**			
MORRO AZUL	19,9		Risaralda	Belen deUmbria	10/09/2016

ANNEX 2. Proposed template to be used as risk treatment plan.

Risk Identification			Risk Evaluation			Risk Control					
Risk Prioritization Number RPN=Severity X Likelihood (<100%) Table 10 (Columns 5x6)	**Process or Work Activity**	**Risk (To be taken from Table 7)**	**Existing Risk Control (Examples) (To be taken from Table 9)**	**Likelihood or Probability (To be taken from Table 7)**	**Impact or Severity (To be taken from Table 7**	**Additional Risk Control Measures (Examples)**	**Severity After Control Measure**	**Likelihood After Control Measure**	**Risk Prioritization Number RPN=Severity X Likelihood (<100%)**	**Follow up by (name) & date**	**Remarks**
			Verification and compliance audits								
			Contractual conditions								
			Review and approval of designs and specifications								
			Inspection, audit and control processes			Contingency plans					
			Investment Portfolio Management			Contractual Addenda					
			Preventive Maintenance			Modifications in Design, Engineering and Specifications					
			Quality assurance, management and standardization			Continence and disaster recovery plans					
			Research and technological development			Structural and engineering barriers					
			Training and training			Communication Plans					
			Supervision								
			Tests and simulations								
			Organizational arrangements								
			Control Techniques								