# Renewables Energies in Colombia and the Opportunity for the Offshore Wind Technology

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## Abstract

This paper displays a review of the literature which shows international actions that have motivated different countries to establish strategies to reduce $C0_2$ emissions and the high dependence on fossil fuels. Additionally, advances and challenges of the offshore wind energy (OWE) are presented through the experiences of several countries. The administrative framework of the renewable energy, the potential of marine energy, and the needs and opportunities of Colombia are shown. The present document gathers technical, economic, administrative and legal information of the renewable energies in Colombia that may be used for taking decisions of different stakeholders.

***Keywords:*** *wind energy, offshore, renewable energy, Colomiba, marine energy.*

## 1. Introduction

Several countries have settled their contribution to the reduction of carbon emission by 2030 where Germany is expected to generate 50% of the global renewables energies. Italy has projected a 20%, Brazil 20% and the United States 20%. The United Kingdom is committed to generating 31% of renewable energies in the world by 2020, India expects to generate 100 GW of solar energy by 2022, and The Arab Emirates expect to generate 24%, including a solar plant of 3 GW (World Energy Council, 2016a). Latin America and the Caribbean have the larger extension and variety of renewables energies in the world; excluding hydroelectric energy, the other energy sources have not achieved an important extraction development. The potential that the region has is higher than 78,000 TW.h (Flavin et al., 2014). The study presented by the Mining Energy Planning Department (UPME, *Unidad de Planeación Minero Energética*), attached to the Ministry of Mines and Energy in Colombia (MINMINAS, *Ministerio de Minas y Energía)*, reported that Peru, Panama, Chile, Mexico, and Brazil have a wind energy capacity installed by 2014, of about 148 MW, 220 MW, 836 MW, 2.3 GW and 5.9 GW, respectively.

Colombia produces 19.5 MW, an amount that compared with the listed nations is not competitive. This capacity from Colombia has not increased since 2003 (UPME, 2015a).

The OWE shows several advantages respect to the onshore wind energy. One of the main advantages is that in the ocean, the wind speed is higher and less unstable, due to the roughness of the sea surface, which is smaller than land (continental) surfaces. The main disadvantages of OWE are the construction and maintenance costs wherein these offshore turbines require an efficient structural design (Cheng, 2002). Weaver (2012) analyzed the commercial appeal of the wind energy market and pointed some considerations about financial values of the life cycle of a wind farm. The research concluded that CAPital EXpenditures (CapEx) could be an objective tool to reduce the cost of energy.

The offshore wind projects generate economic benefits but at the same time present risks associated with the industry. Gatzert and Kosub (2016) reviewed the risks and solutions of renewable energy projects. They discussed the risks of onshore and offshore projects from the investor perspective and the solutions of risk handling of the European energy market. They concluded that constructive risks would be reduced with technological development. Also, to ensure sustainable development of renewable energy market, it is necessary to guarantee the stability of policies and regulations; the improvement of the international cooperation, for instance, the World Bank, offers guarantees of partial risks in some risk policies.

This research shows the possible scenarios of renewable energies according to the World Energy Council approach, and the highlights of the recent energy trilemma index results. Also, the research presents different experiences and projects about OWE. The section 4 of this study presents the official organizations and the administrative framework of the renewable energies in Colombia. Finally, the section 5 presents several studies that show the potential of marine renewable energies in Colombia and the section 6 shows the needs and challenges that Colombia has to overcome, to take advantage of the potential of renewable energies.

## 2. Methods

This study required scientific, legal and administrative information related to the progress of the OWE in the world. Also, information of the renewable energy framework in Colombia, and the challenges and opportunities for the renewable energy were reviewed. This study was performed using online scientific databases such as Science Direct, Research Gate and official databases of the Colombia government: Ministry of Mines and Energy, Planning Unit Energy Mining, Superintendence of public services, Superintendence of Industry and Trade, Institute of Planning and Promotion of Energy Solutions for non-interconnected zones, Ministry of Environment and Sustainable Development, and Institute of Hydrology, Meteorology and Environmental Studies (IDEAM). In addition, through the Google search engine, were downloaded online books and proceedings related to the renewables energies in Colombia and overseas. The keywords considered in the literature search in English and Spanish were the following: OWE, renewable energy, marine energy, Colombia, Colombian Caribbean, energy policy framework, energy regulations, and energy progress. The Science direct database showed 1987 articles related to OWE, 188,394 for renewable energy, 189,674 for marine energy, Colombia, 8631 for Colombian Caribbean, 114,921 for energy policy framework, 448,732 for energy regulations, and 642,491 for energy progress. Due to the number of results, this study selected the papers related to the main experiences and progress of the energy industry of several locations in Europe, China, United States, Latin America, Middle East and Asia.

## 3. The World Energy Council approach.

The World Energy Council proposed three possible scenarios for the energy market to the 2050 year: Modern Jazz, Unfinished Symphony and Hard Rock (World Energy Council, 2016b). The Modern Jazz is a focused approach to achieve individual access and accessibility to the energy through the economic development. This approach considers creating new market mechanisms, generate technology innovation and open access to the energy for everyone. The Unfinished Symphony is a government-led policy to achieve the sustainability through coordinated practices and international policies. The approach mentioned above is characterized by strong policies, long-term planning, and concerted climate action. The Hard Rock approach is considered as a fragmented approach motivated by the desire of the energy security in a world with low global cooperation. Therefore, their policies or strategies have a local perspective. Considering the three scenarios of renewable energies in the world (Table 1) is showed that Unfinished Symphony allows the highest development of renewable energy (RE) production to 2030, being the wind energy the most developed in the four scenarios.

Table 1. Growth of the renewable energies in the World considering the three approaches.

| Electricity generation (TW.h) | 2013 | | 2030 Modern Jazz | | 2030 Unfinished Symphony | | 2030 Hard Rock | |
|---|---|---|---|---|---|---|---|---|
| | TW.h | % | TW.h | % | TW.h | % | TW.h | % |
| Coal | 9,595 | 41.17 | 8,960 | 27.85 | 7,741 | 25.09 | 9,684 | 31.64 |
| Coal (with CCS) | 0 | 0.00 | 20 | 0.06 | 95 | 0.31 | 0 | 0.00 |
| Oil | 1,048 | 4.50 | 560 | 1.74 | 381 | 1.23 | 733 | 2.40 |
| Gas | 5,081 | 21.80 | 9,292 | 28.88 | 7,014 | 22.73 | 7,740 | 25.29 |
| Gas (with CCS) | 0 | 0.00 | 0 | 0.00 | 82 | 0.27 | 0 | 0.00 |
| Nuclear | 2,478 | 10.63 | 3,327 | 10.34 | 4,367 | 14.15 | 3,864 | 12.62 |
| Hydro | 3,790 | 16.26 | 4,816 | 14.97 | 5,109 | 16.56 | 4,825 | 15.76 |
| Biomass | 461 | 1.98 | 1,069 | 3.32 | 1,187 | 3.85 | 844 | 2.76 |
| Biomass (with CCS) | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 |
| Wind | 635 | 2.72 | 2,540 | 7.90 | 2,918 | 9.46 | 1,983 | 6.48 |
| Solar | 145 | 0.62 | 1,369 | 4.26 | 1,694 | 5.49 | 793 | 2.59 |
| Geothermal | 72 | 0.31 | 210 | 0.65 | 262 | 0.85 | 133 | 0.43 |
| Other | 3 | 0.01 | 8 | 0.03 | 5 | 0.01 | 8 | 0.03 |
| Total Renewables | 851 | 4.00 | 4,120 | 13.00 | 4,874 | 16.00 | 2,908 | 10.00 |
| Total | 23,307 | 100 | 32171 | 100 | 30,854 | 100 | 30,605 | 100 |

Adapted from Vargas (2017)

The three approaches consider decreasing the $CO_2$ emissions from 31 GTon to 13 GTon through the Unfinished Symphony, from 36 GTon to 23 GTon through Modern Jazz and from 37 GTon to 34 GTon through Hard Rock (Vargas, 2017). The three approaches applied to the Latin America and the Caribbean indicated that the wind energy is the greatest contributor to the renewable electricity generation. In 2014, the wind energy generated 19 TW.h with 1.47% of participation in the energy market, the solar energy produced 1 TW.h with 0.08% of participation, geothermal produced 4 TW.h with 0.31% of the contribution, and others technologies generated 1 TW.h with 0.08% of participation. The Unfinished Symphony approach is identified as the most effective strategy compared to the other approaches, which would produce 191 TW.h in 2030, being the 11% of participation in the energy market (Vargas, 2017).

The world energy council published in 2016 a list of the top 10 countries in the energy trilemma index (environmental sustainability, energy equity, and energy security). The top three countries in the environmental sustainability dimension of the trilemma were Philippines, Iceland, and Colombia. Although these three countries have high geothermal or hydropower capacities, they have an important challenge to diversify their energy systems. In addition, they must strengthen the institutional framework that motivates the creation and implementation of policies through research (World Energy Council, 2016b).

## 4. Progress and challenges in the offshore wind industry

Due to the high OWE potential for exploitation, several countries in Europe decided to perform technical and economic consultancies for setting the extraction and distribution feasibility of this renewable energy in their States. According to the review of the situation and projection of the OWE in Europe carried out by Rodrigues et al. (2015), the installed yearly capacity grew 36.1% from the construction in 2011 of the first offshore wind project; by 2015, the installed capacity was 7,748 MW and 3,198 MW of construction capacity.

The European Wind Energy Association informed in 2015 that 3,230 turbines had been installed in Europe, distributed in 84 offshore wind farms; it was reported a generation of 11,027 MW of total capacity, an average water-depth installation of 27.2 m and a mean average distance to the coastline of 43.3 km (Ho et al., 2016). According to Rodrigues et al., (2015) is expected that, shortly, Germany and UK remain as the leaders of the offshore wind industry in the world; Germany in 2015 reported a 10.5 GW installed capacity and UK from 2008 begun its offshore development program to increase the total capacity to 28.9 GW. Currently, UK is considered as a world leader in the OWE extraction. Kota et al. (2015) compared the installed capacity and potential of the offshore wind industry, and their conclusions mentioned that the UK to 2016 had more than twice the installed capacity of any country in the world.

Ireland in 2002 through a consultancy study decided to establish the costs and benefits that could generate the OWE. The study evidenced the political barriers and financial restraints in that year. Ireland wanted to reduce the annual emission of 2400 Ton of $CO_2$ and the import of fossil fuel up to 100,000 euros with the implementation of OWE technology. The consultancy report recommended a demonstrative or pilot program, which would improve the confidence of investors, financial creditors, and technology developers (SEI, Sustainable Energy Ireland, 2002). Holland in 1972 suffered the first oil crisis, what motivated this country to diversify its technologies and industries of energy extraction. Verhees et al. (2015) presented details about the actions taken by Holland in 1986 to expand the energy industry. The research pointed several events related to the initiative of the country to promote the OWE. As a result, Holland achieved through an energy company to build the first offshore wind farm in the North Sea, with an installed capacity of 100 MW. The report presented by the Netherlands Enterprise Agency in 2015 indicated that Holland has an installed capacity for OWE of 1,000 MW, and is working to increment the capacity to 4,000 MW for the 2023 (Netherlands Enterprise Agency, 2015).

In 2012, it was estimated an installed capacity of 4 GW of OWE in the marine zones in the north of Europe and was planned to increment the installed capacity to 40 GW in 2020 and 150 GW in 2030. The projections of installed capacity of tides and waves energy by 2020 are 2 GW, what shows the priority of OWE regarding others marine renewable energies (VLIZ, Vlaams Institute Voor de Zee, 2015). The European Union between 2012 and 2016 carried out the MERMAID project, which tried to develop the next generation of multipurpose offshore platforms for marine energy extraction and mariculture. The project was integrated by 11 universities, 8 research centers, 5 large companies and 4 small and medium-sized enterprises (SMEs). Several projects had relation to MERMAID and were the followings: SI OCEAN, MARINET, SOWFIA, TROPOS, H2OCEAN, DEMOWFLOAT, MARINA platform, HiPRWind Project, UPWIND Project, PolyWEC project, ORECCA, SAFEWIND, 7MW-WEC-BY-11, NORSEWIND, PROTEST, RELIAWIND, TOPFARM, WAVEPORT, SEANERGY 2020 (VLIZ, Vlaams Institute Voor de Zee, 2015).

In Spain, there are not energy policies that guarantee a stable regulation frame that protects the interests of the investors, leading to a low motivation to develop the OWE technology. Contrary, the syndicate of renewable energies in France try to generate 15 GW for 2030 through offshore wind turbines (Colmenar-Santos et al., 2016). The French Government committed to Europe to generate 6,000 MW of OWE by 2020. In 2013, France produced 3,000 MW of OWE, but according to the inspection of the established projection in 2013, the expectation will not be achieved in 2020. As a result, France decided to extend the accomplishment of the objective to 2030, to increase the OWE production to 15,000 MW and to create 30,000 new job positions (Syndicat des énergies renouvables, 2013).

Turkey shows an annual increase of 8% of energy demand. Therefore, this country had to import the 72% of its energy. While the energy potential was 48,000 MW, the installed capacity for exploitation to 2014 was 2,959 MW (Kaplan, 2015). It has been identified that the complexity and slowness of government administrative processes have limited the development of OWE technology in Turkey. However, the Turkish Wind Energy Association (TWEA) commits to producing 20 GW by 2023 through the improvement of the national energy network (GWEC, Global Wind Energy Council, 2016). The department of energy of the United States reported that in 2030 the country would attend the 20% of the domestic demand, through the development of the installed capacity of wind energy industry. The wind energy potential that will attend the future demand is 251 GW, which 54 GW will come from offshore wind farms located in shallow waters (U.S. Department of Energy, 2008).

Due to the coastal wind farms are more energy efficient, China plans to shift the energy extraction from inland to offshore. Therefore, that country must promote a moderated long-term growth of the offshore wind power (J. Zhang et al., 2017).

South Korea plans to install the first offshore wind farm by 2019. The project is supported by public and private resources, with 92.7 billion of dollars (USD) available to generate 2500 MW of energy (Lee et al., 2013). Nesamalar et al., (2017) analyzed the status, barriers, and potential of renewable energies in the Tamilnadu state (India), and indicated that the state planned to generate 10.65 GW of renewable energy by 2023, which 127,428 MW are associated to OWE (WISE, World Institute of Sustainable Energy, 2012). Azerbaijan installed the first two offshore wind turbines in the waters of the Caspian Sea; the project reported a 1.7 MW of installed capacity and avoided the utilization of 2.5 mln $m^3$ of natural-gas (Baker and Safarzade, 2009). The Renewable Energy policy framework in Colombia.

## 5. The Renewable Energy policy framework in Colombia

In Colombia, the Regulation Commission of Energy and Gas (CREG) regulates and promotes a sustained development of the provision of public utilities for electric energy, fuel gas and public liquid fuel services (CREG, 2018a). The CREG has created and integrated several guidelines to regulate the Non-conventional sources of renewable energy (FNCER, *in Spanish*) as seen in Table 2.

**Table 2.** Guidelines and methodologies for the associated activities to produce Non-conventional sources of renewable energy in Colombia.

| Guideline/Methodology | Description |
|---|---|
| Resolution CREG 85 (CREG, 1996), and 005 (CREG, 2010) | About surplus sales of co-generation. |
| Resolution CREG 153 (CREG, 2013) | About fuel supply contracts of agricultural origin for the reliability charge. |
| Resolution CREG 132 (CREG, 2014a) | Methodology to estimate the maximum electricity that can produce a generation plant permanently during low hydrologic conditions in one year (ENFICC, *Energía Firme para el Cargo por Confiabilidad*) for geothermal plants. |
| Decree 2469 (CREG, 2014b) | Self-generation for big scale. |
| Resolution CREG 024 (CREG, 2015a) | Self-generation for big scale. |
| Resolution CREG 061 (CREG, 2015b) | Methodology ENFICC for wind plants. |
| Resolution UPME 0281 (UPME, 2015b) | Power limit for self-generation in small scale |
| Resolution CREG 243 (CREG, 2016a) | Methodology ENFICC for solar plants. |
| Resolution CREG 026 (CREG, 2016b) | Transient dispositions to adapt the entrance of new generation plants to the system. |
| Document CREG 161 (CREG, 2016c) | Regulatory alternatives for the FNCER. |
| Decree 348 (MINMINAS, 2017) | Self-generation for small scale. |
| Report 013 (CREG, 2017) | About market proposals for short-term, contract market and reliability charge (CxC, *Cargo por Confiabilidad*) and their implications over FNCER. |
| Resolution CREG 015 (CREG, 2018b)(CREG, 2018b) | Establishment of a methodology for reimbursement of distribution activity of energy to the Interconnected National System. |

Source: CREG (2018a)

To reduce the $CO_2$ emissions, Colombia decided to improve the national economic development avoiding the increment of the greenhouse gas (GHG) emissions (2012). Then, between 2013 and 2015 the Ministry of Environment and Sustainable Development (MADS, *Ministerio de Ambiente y Desarrollo Sostenible*), created the Sectorial Action Plans (PAS, *Planes de Acción Sectorial de Mitigación para el Cambio Climático*), to integrate the other Ministries into the guidelines of MADS. In 2015, the PAS were approved through the law 1753 of 2015 for the period 2014-2018 (Senado de la República de Colombia, 2015); the Green Growth chapter gives the authorization to the other Ministries to generate the implementation plan of PAS and the sectorial adaptation plans. In the COP21 held in Paris, Colombia was committed reducing the 20% of GHC emissions (67 million Ton of $CO_2$) to 2030. Later, in February 2016 it was created the National System of Climate Change (SISCLIMA, *Sistema Nacional de Cambio Climático*), to manage the climate change in Colombia. As a result, SISCLIMA through the Intersectoral Commission on Climate Change (CICC, *Comisión Intersectorial de Cambio Climático*), formulated the strategies to achieve the agreement of Paris (Murillo, 2017). The authorization of projects to generate energy from FNEC is given by two entities of MADS in Colombia: The National Agency of Environmental Licenses (ANLA, *Autoridad Nacional de Licencias Ambientales*) and the Regional Environmental Corporation (CAR, *Corporación Autónoma Regional*). The ANLA controls the exploration and generation projects of FNEC virtually contaminants, with an installed capacity equal or higher than 100 MW. The CAR controls projects with an installed capacity equal or higher than 10 MW and less than 100 MW (Murillo, 2017).

Colombia established the action plan 2010-2015 of the Rational and Efficient Use of Energy and Non-Conventional Sources (PROURE, *Programa de Uso Racional y Eficiente de Energía y Fuentes No Convencionales*), to consolidate the culture of sustainable management of natural resources along the energetic chain (Prias Caicedo, 2010). The plan pretended to generate the economic, technical and regulatory conditions to encourage the energy market in Colombia and strengthen the national institutions and private organizations to develop subprograms and execute renewable energy projects. After the UPME presented the "Expansion Generation Plan 2015-2029", to guarantee the energy reliability, which pretends to install the new hydroelectric capacity and the growth projection of minor plants, integrating conventional technologies such as the thermic and hydroelectric plants with non-conventional renewable energies (wind, geothermic, biomass and solar). The plan pretends to motivate the generation of 1.2 GW from wind energy in La Guajira region. Additionally, the plan analyzed the distribution of new 3.12 GW of wind energy in La Guajira region through the integration of new technologies (UPME, 2016).

Since the enactment of Law 697 of 2001 the use of renewable energy sources in Colombia have acquired legislative status; the development programs to encourage and promote companies that import or produce parts or equipment that use the renewable energies was established as a duty of the National Government. The Ministry of Energy and Mines formulates guidelines for policies, strategies, and instruments for the promotion of non-conventional sources of energy (National Government, 2001). After 17 years the impact of the law 697 has been limited, due to in the 2017 year, Colombia barely reached the 2% of the installed capacity and the 1.2% of electricity generation of non-conventional renewable energy.

In Colombia, the law 1715 was promulgated to "promote the development and use of non-conventional sources of energy, mainly those of a renewable nature, in the national energy system, through its integration into the electricity market, its participation in non-interconnected areas and other energy uses". (UPME, 2017a). The law 1715 was a milestone for the development of the renewable non-conventional energy sources projects. The proposed incentives in that law are: a) annual reduction of income in projects to promote research, development and investment in the field of the production and use of energy from FNCER, as well as the efficient management of energy, b) exclusion of the Value Added Tax (VAT) to encourage the use of energy from FNCER, c) exemption from payment of Tariff Rights for new investments in new FNCER projects and d) accelerated depreciation of assets for the generation activity from non-conventional energy sources (Gaona et al ., 2015). The foreseeable impact of these incentives has been assessed by Castillo et al., (2017) as a very positive, however Olaya et al., (2016) pointed out that some incentives that have been successful in other countries have been ignored. Up to 2017, 221 FNCER application projects have been certified, with an estimated generation capacity of 1,240.88 MW, which are in different stages of execution (UPME, 2017).

Although Law 1715 is an important step forward in the development of the application of the no conventional energy sources in Colombia and its insertion in the Interconnected National System, Pereira (2016) considered limited scope the Law 1715 because only promotes activities to the application of the no conventional energy sources in Colombia. Also, Olaya et al., (2016) mentioned that the law does not indicate mechanisms for the implementation of the FNCER projects.

Since 2006 it has been pointed the shortcomings in the regulation and the lack of adequate tariffs (Ruiz and Rodrigez-Padilla, 2006), a situation that is still maintained (Edsan 2017; Román et al., 2018). There is uncertainty regarding the implementation of the non-conventional renewable sources because the lack of regulations for the rate of adoption, prices, and problems of security of supply in the Colombian energy market (Jimenez et al., 2016). The lack of a methodology and rules to calculate the contribution of wind and other energy sources limited the estimation of reliability payments in energy auctions (Botero et al., 2010). Olaya et al., (2016) has also criticized the fact that Law 1715 leaves unresolved structural problems of the electricity market, that lead the non-conventional renewable energy sources to compete under disadvantageous conditions against the conventional energy sources. Although there is a national indicative plan (UPME, 2016b), which establishes the actions and sectoral measures for the fulfillment of the goals in the energy sector by 2022, In the case of the no conventional renewable source there are no mandatory compliance targets established. Then, Roman et al. (2018) strongly recommend following the example of countries such as Chile, Mexico and Argentina that have established by law the goal of 10% of electricity generation from non-conventional energy sources. Medina et al. (2013) indicated that evaluation of UPME for the use of the non-conventional energy sources in Colombia is in a primary state. Also, the technical developments, capacity and experience have not been achieved, what may delay the implementation of the Law 1715.

## 6. Marine renewable energies in Colombia

The World Bank in 2010 pointed that the dynamics of the wind energy availability in Colombia is complementary to the hydroelectrical energy regime. It means that during dry seasons, Colombia presents maximum wind speeds. According to the report, wind speed reaches 9 m/s [32 km/h] at the height of 50 m, generating possibilities to wind energy exploitation (ESMAP, 2010). Colombia has a wind potential of 18 GW just in La Guajira onshore areas, with the capacity to attend twice the domestic energy demand (Pérez Bedoya and Osorio Osorio, 2002). The annual mean wind speed map at surface level in Colombia was recently updated, where it is possible to identify the highest velocities about 15 m/s close in the coastal and offshore areas of the Atlántico and Guajira department **Erro! Fonte de referência não encontrada.**(IDEAM, 2018).

The marine renewable energy potential for Colombia (waves, tides, currents, wind and thermohaline gradients) had been studied thoroughly in the last decade (Devis-Morales et al., 2014; Ortega, 2010; Alvarez-Silva and Osorio, 2015; Realpe-Jiménez et al., 2012; Osorio et al., 2016). The studies mentioned above have shown relevant information about marine renewable energy in Colombia, mainly currents, waves, tides and thermohaline gradients. These studies recommend improving the knowledge about the availability and quality of the mentioned renewable sources as well as the technical and economic availability for exploitation. However, there are no public evidence about detailed OWE information for specific places, nor technical, financial feasibility studies for installation, extraction, and operation of offshore wind farms in Colombia.

## 7. Needs, challenges, and opportunities for Colombia

According to the World Energy Council (2014), the Colombian electric system is vulnerable to climatic phenomena that can decrease the water availability. The El Niño phenomenon has generated droughts during the periods 1991-1992, 2002-2003 and recently during 2015-2016. The report published by

IDEAM mentioned that the most intense period led to Colombia to an energy saving regime, to avoid an imminent electrical rationing. Low water levels of dams during El Niño (2015-2016), the limited gas offer, and the high oil prices put at risk to the Colombian electric system in 2016 (Dinero, 2015). The transition of Colombia to the renewable energy has begun, and it is evidenced in the recent decisions taken by the public and private sectors (CREG, 2018b). Contreras and Rodríguez (2016) developed a proposal to improve the policies of the renewable energy management, through mechanisms of articulation, distribution, and financing of private sectors with public participation. They consider that private sector must facilitate resources for the execution of the project, and the public sector must acquire the responsibility of regulating and distributing the energy service. As stated by Botero et al. (2010) and Vergara et al. (2013), some incentive mechanisms are needed to increase wind power implementation; tax exemptions is one way but not the most efficient. In this regard, the reform proposed by Contreras and Rodriguez (2016) considers incentives that generate interest to develop renewable energy projects. The main recommendations given in the reform are:

- Definition of the distributed generation as part of the power supply chain.
- Definition of the mechanisms to incentive the renewable energy uses according to the characteristics of the country where the potential menaces to the wind energy project can be mitigated.

Franco-Cardona et al. (2015) pointed that to study the economic effect generated by the implementation of non-conventional renewable energies, it is necessary to analyze the effect of the cost reduction in the energy rates through subventions. The reduction of hydroelectric energy during El Niño (2015-2016) and the elevated costs of oil fuel in that period (Dinero, 2015) motivated to increment and diversify the domestic energy offer. Castro Ferreira (2017) indicated that the guarantee of an efficient and sufficient electricity offer requires a reliable infrastructure, and the expansion of FNCER. Then, to enhance the offer are necessary administrative mechanisms through contracts as "Take or Pay," "Energy Purchase Agreements (EPAs), "Pay the generated" and "Green Bonus." Zuluaga and Dyner (2007) analyzed simulations of the Colombia market and concluded that direct subsidies have a major effect on the renewable energy technology diffusion than initiatives such as fiscal policies (tax exemptions).

Ortiz (2017) specified that the development of FNCER requires the retribution of self-generation surpluses, the improvement of information about FNCER potential and availability, the definition of additional mechanisms to diversify the electric matrix, the adjustments of market mechanisms (bilateral contracts, reliability charge, auctions), and a normative for the exploitation of geothermal resources. Additionally, some challenges to overcome were identified for the FNCER development: integration of climate change policy to the energy policy, coordination of licensing processes for generation and transmission, intermittency of FNCER, and development of projects to expand the FNCER.

The association of Renewables Energies (Ser Colombia, *Asociación de energías renovables Colombia*) sent several communications to the MADS and ANLA, about the environmental licensing requirements for FNCER and Thermal (Fossil fuel) in Colombia. The communications pointed that requirements for FNCER could be reduced or modified due to the low environmental and social impact compared to Thermal plants. Ávila (2017) highlighted some examples of the mentioned modifications suggested by Ser-Colombia:

- Localization: General and not detailed with planimetry and altimetry.
- Characterization for structural elements: it is not required such a detailed characterization like fails, minor discontinuities, and others; this type of projects just require excavations of 1.5 m of depth or less and less than 0.3 m of diameter.
- Aquifer vulnerability: It is only necessary an evaluation of aquifer vulnerability to contamination if the FNCER project requires water.
- Do not demand studies for local meteorology and wind modeling, due to the contaminant emissions during the construction phase are low.

The UPME reported 160 projects applying to benefits in February 2017, where 136 correspond to solar energy, 8 to hydroelectric, 8 to biomass, 6 to wind, 2 for geothermal energy and 9 on the list; about these projects 94 were approved, 46 under review, 25 in registering, and 4 rejected. The applying projects represent a total capacity of 1,214 MW, which 560 MW are for biomass, 376 MW for Eolic, 195 MW for geothermal energy, 63 MW for solar, and 12 MW for hydroelectric energy (Valencia, 2017). The possible events of the distribution of generated additional capacity and associated cost are related in Fig. 1, where is possible to observe that condition 3 showed the lowest investment costs from all conditions.

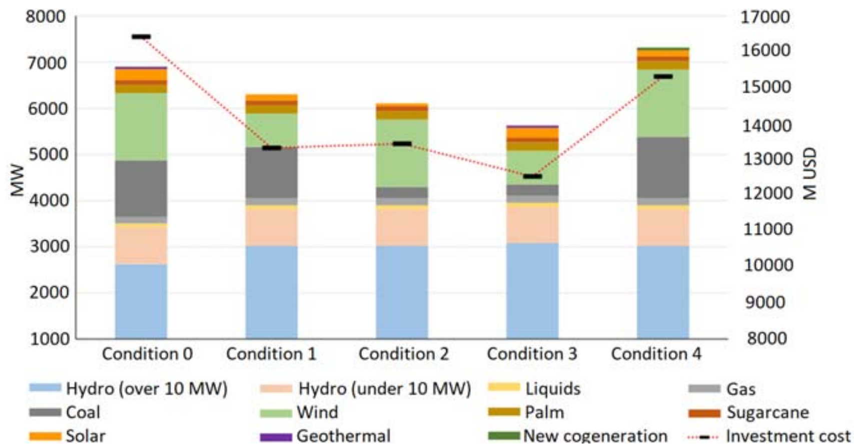


**Fig. 1.** Investment cost for additional capacity. Modified from: Valencia (2017).

The characteristics of each condition are shown in **Erro! Autoreferência de indicador não válida.**, which condition 2 suggests more additional expansion for wind energy and no additional expansion of coal, and condition 3 suggests more additional expansion for solar and geothermal energy and zero additional expansion for coal.

**Table 3.** Present and future scenarios according to conditions base installed capacity (MW) and additional expansion (MW).

| | | Condition 0 | | Condition 1 | | Condition 2 | | Condition 3 | | Condition 4 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | Base | Additional expansion | Total | Additional expansion | Total | Additional expansion | Total | Additional expansion | Total | Additional expansion | Total |
| Hydro (over 10 MW) | 10,890 | 1427 | 13,517 | 1,824 | 13,914 | 1,824 | 13,914 | 1,878 | 13,969 | 1,824 | 13,914 |
| Gas | 3,509 | 147 | 3,656 | 147 | 3,656 | 147 | 3,656 | 147 | 3,656 | 147 | 3,656 |
| Coal | 1,344 | 970 | 2,564 | 859 | 2,453 | 0 | 1,594 | 0 | 1,594 | 1,080 | 2,674 |
| Hydro (under 10 MW) | 745 | 793 | 1,539 | 793 | 1,539 | 793 | 1,539 | 793 | 1,539 | 793 | 1,539 |
| Cogeneration | 117 | 285 | 402 | 285 | 402 | 285 | 402 | 285 | 402 | 331 | 448 |
| Wind | 0 | 1,456 | 1,456 | 727 | 727 | 1,456 | 1,456 | 727 | 727 | 1,456 | 1,456 |
| Solar | 0 | 234 | 234 | 130 | 130 | 64 | 64 | 210 | 210 | 130 | 130 |
| Geothermal | 0 | 50 | 50 | 0 | 0 | 0 | 0 | 50 | 50 | 0 | 0 |
| Others | 0 | 0 | 88 | 0 | 88 | 0 | 88 | 0 | 88 | 0 | 88 |
| Total | 16,606 | 5,362 | 23,506 | 4,765 | 22,909 | 4569 | 22,713 | 4,091 | 22,235 | 5,761 | 23,904 |

Source: Valencia (2017)

The OWE technology is still not considered as an interesting alternative for the FNCER projects. This technology requires a continuous research to reduce the associated costs and also, requires a specific research to evaluate the OWE potential to increment the domestic offer in Colombia. Accordingly, it is necessary specialized personnel (interdisciplinary professionals and technicians) that support the research and development of OWE industry. Despite the authors performed two studies carried out in Colombia related to the design of offshore wind turbines (Rueda-Bayona, 2015, 2017) there are some limitations to wind energy diffusion as referred by Edsand (2017).

## 8. Conclusions

Colombia must increase the knowledge of the availability of the renewable sources and the technical and economic feasibility of the marine renewable projects. Also, Colombia needs to identify the potential effects due to the non-transition to the clean energies and the costs of implementing offshore renewable technologies. The onshore wind energy at present is dominated by Europe, where the land availability is scarce, and some communities do not accept the installation of these structures easily. As a result, the wind energy sector is increasing the number of offshore wind projects, not only by land restrictions but also because the OWE is abundant and a good quality source.

The feasibility of offshore energy projects need specialized personnel, then, Colombia must define an integrated industry-academia policy. Colombia can establish tax incentives and financial alternatives to the development and innovation companies that will allow the implementation of OWE pilot projects with the support of universities and research centers. The results of the pilot projects will define the mechanisms to implement the design, production, installation, generation, maintenance and dismantling processes and methodologies. The Colombian State needs to improve the communication with the different actors of society (communities, fishers, environmentalist), and the economic sectors associated with the tourism, mariculture, energy, naval, port, and security.

Finally, the OWE technology will reduce the dependency of fossil fuel and will complement the generation of electricity in Colombia, when hydroelectric systems cannot guarantee the offer during the more recurrent droughts periods due to the El Niño phenomena. Now is the opportunity for Colombia to be a relevant energy exporter and leader in OWE technology.

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