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Article

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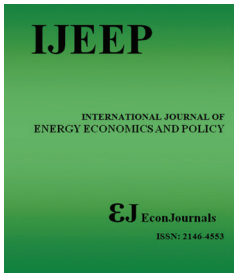

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Evolution, Challenges, and Perspective in the Implementation of Projects with Renewable Energy Sources: Colombia Case

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ABSTRACT

This work quantifies the evolution in the implementation and development of renewable energies in Colombia, as well as evidence the current challenges and development prospects. The high demand for electricity in Colombia is increasing due to the great increase in population, industry and commerce, which generates greater energy consumption and as a consequence economic, social and environmental problems. The objective of this study was to analyze the behavior of the energy projects submitted to the Mining Energy Planning Group (UPME) during the last 15 years until July 2022, as well as to study the research areas with the highest performance. Technology and the corresponding radiation intensity in addition, it shows an historic information about the projects presented both not in force as of the date of closing of this investigation, classified according to their source, according to their range of power and according to its stage of implementation, finally, we made a synthesis of the new regulations governing the motivation and implementation of projects with renewable energy sources, being as this work a very good source of reference for further studies of the implementation of renewable energy sources in Colombia.

Keywords: Renewable Energies, Sustainable Development, Climate Change, Clean Energy Policies, CO_2 Mitigation
JEL Classifications: O13, Q42, Q43, Q47

1. INTRODUCTION

There is a universal consensus that electrification and/or energization is vital for the development of areas of developing countries, and that certainly has no discussion. It is clear that the absence of electricity stops economic development. On the contrary, the industrialized countries have shown very significant progress on this issue, as an example of this, countries such as China have proven successful in electricity and rural development in their areas (Moreno and Larrahondo, 2021). However, for developing countries, there is an obvious problem, especially in their rural and/or remote areas (Ancaya-Martínez et al., 2022a). One of the main reasons for this is the absence of government support for rural development, however, in recent years, multiple technological, technical projects have appeared which seek to guarantee electricity sustainability in the implementation area (Moreno et al., 2022). All energization projects and more when these are carried out with the implementation of renewable energy sources require a process of technology transfer and social appropriation of knowledge, in which communities feel included and part of the solution (Christian Moreno et al., 2022). Law 855 of 2003 in Colombia recognizes as Non-Interconnected Zones (ZNI) all municipalities or localities that are not connected to the National Interconnected System (SIN) (Hernández et al., 2021). According to the Institute for Energy Planning and Solutions for Non-Interconnected Zones (IPSE), isolated areas in Colombia are equivalent to approximately 52% of the country. These are approximately 1400 localities, characterized by low payment

capacity, low average consumption and high costs of providing electricity service, among other factors (Rocha et al., 2022). Likewise, the communities living in these areas have important properties of ethnic minorities (indigenous, Afro-Colombian and native islanders), so a social and economic characterization is required prior to the implementation of any project (Ramírez-Tovar et al., 2022). In recent years different energy projects have been developed in the rural sector and non-interconnected areas in Colombia, the objective of these projects is to provide clean technologies to people in remote areas to increase their productive capacities and improve their quality of life (Gielen et al., 2019). The productive processes in these areas stimulate economic growth, generating new income alternatives that result in social welfare. However, the implementation of these processes is difficult (Howie and Atakhanova, 2022). Communities don't have continuous, reliable power systems and electric service, or worse, it doesn't exist at all. Due to the geographical conditions of Colombia, renewable resources are an excellent option to develop electricity service (Ediger, 2019).

It is no secret that the depletion of traditional energy sources (fossil fuels) has led most countries in the world to find solutions in alternative energies (OJEDA Camargo et al., 2017). Colombia has great potential in the generation of this type of energy due to its geographical position and is already working on it, alternative or renewable energies are those that take direct advantage of resources considered inexhaustible such as the sun, wind, bodies of water, vegetation or the interior heat of the earth (Barrera et al., 2021) (Ojeda et al., 2017). The International Energy Agency (IEA) says that the basis of modern life in the world depends on 80% of oil and that as countries industrialize and their populations increase, so does energy consumption (Guzman and Henao, 2022). In Colombia, primary energy production comes from hydroelectricity, due to the abundance of water in most areas of the country, and in a second place from fossil fuels (oil, gas and coal), whose reserves are already being depleted (Ruiz et al., 2021). That is why the National Government in recent years has invested in the development and application of alternative energy production technologies, which work with renewable resources, to solve the problem of the global energy crisis and contribute to a cleaner environment, however, according to the National Mining energy Planning Unit (UPME), renewable energies currently cover about 20% of global electricity consumption (Guzman and Henao, 2022) (Villada et al., 2021).

2. METHODS

For this investigation, a historical sweep was made taking as a start date the year 2007 and as a culmination date July 2022, for this a series of data downloads from different sources of information was carried out, among which we highlight official reports of the Colombian government, official reports of the UPME energy mining planning unit official reports from experts in the XM energy market, as well as reliable sources indexed internationally such as Scopus, Wos and Science Direct. The number of projects presented by each energy source, the power to be developed, the phase in which it was currently located, the number of projects not in force and those in force at the closing date of this investigation were investigated. This methodology allowed to create and organize a large database with reliable information, which was structured in such a way that it can be interpreted and studied in the best possible way, serving as a reference to future research.

2.1. Renewable Entities and Their Implementation in Colombia

Each of the energies involves different types of technologies with which energy is obtained in the form of electricity, motive force, heat or fuels. They have been classified into six main groups: Solar Energy, Wind Energy (Wind), Biomass Energy, Hydropower, Ocean Energy and Geothermal Energy.

2.2. Solar Energy

It is the primary source of light and heat on earth, for this reason it can be considered as a renewable source; to generate it, the solar radiation that reaches the Earth is used as a source. This type of energy is free, generates no emissions and is silent (Abdulgalil et al., 2019). In addition, it is one of the few renewable technologies that can be integrated into the urban landscape and is useful in rural areas that are difficult to access. In Colombia it could be generated on a larger scale in the areas of Magdalena, La Guajira, San Andrés and Providencia (Alemam and Al-Widyan, 2022).

2.3. Wind Energy

Wind is moving air, an indirect form of solar energy, this movement of air masses is caused by temperature difference caused by solar radiation on earth. When the air is heated, its density becomes lower and rises, while the cold layers descend, thus establishing a double stream of air. Wind energy can be transformed mainly into electrical energy by means of wind turbines, or into motive force using windmills (Ancaya-Martínez et al., 2022b). It is a safe and free energy, but it has the disadvantages that the wind speed is variable and unreliable, wind turbines produce noise and wildlife can be affected, since there is a risk that birds will fall into them and die. In Colombia, the northern zone has the best potential to generate this resource. For example, in Alta Guajira, Empresas Públicas de Medellín (EPM) put into operation the first wind farm, Jepirachí, with 15 wind turbines that contribute 19.5 megawatts to the National Interconnected System (Magazine, 2017).

2.4. Biomass Energy

Biomass is any organic material from living things that can be used to produce energy. It is produced by burning biomass, such as wood or plants. They use technologies that depend on the amount and class of biomass available. With the main transformation systems, fuels, electrical energy, motive force or thermal energy can be obtained (Perez-Moscote and Tyagunov, 2022). This type of energy emits little carbon dioxide and could be a solution to alternative methods of disposing of waste (garbage burial and burning outdoors). The difficulty is that it requires high capital investment and its profitability would only be seen in the long term. In Colombia, there are studies of biomass production with cane bagasse, which is estimated at an annual production of 1.5 million tons, and rice husk, with which more than 457,000 tons are produced per year. The most suitable areas to generate this energy are the Santanderes, the Eastern Plains and the Atlantic Coast (Guliev et al., 2021).

2.5. Water Power

It is the one that uses as a source, the force of the water of rivers and lakes. It is transformed by hydraulic generation plants and generates electricity. Hydroelectricity is a highly efficient method of generating electricity and does not pollute. It is only advisable for countries that have appropriate climates and topographies, such as Colombia, where there is a great development of these infrastructures (Kahouli et al., 2022). To generate this type of energy, dams must be built, which can include the diversion of the course of rivers, flooding of arable land and the displacement of people. On the other hand, wild habitats are affected and fish can die trapped in turbines (Ancaya-Martínez et al., 2022a).

2.6. Energy from the Oceans

The oceans cover more than 70% of Earth's energy. In them you can find two types of energy: thermal that comes from solar heating and mechanical from tides and waves (Martínez-Ruiz et al., 2022). The sun warms the surface of the oceans in a very high proportion, compared to the deep areas, in this way it creates a difference in temperatures that can also be exploited, but is insecure due to the phenomena to which the oceans are subject. Colombia, according to the UPME, has an estimated potential in the 3000 km of Colombian coasts of 30 GW (González, 2015).

2.7. Geothermal Energy

It comes from the heat coming from the center of the earth. It is transformed by very deep drilling to use the heat force beneath the earth's surface to produce electricity (Guzman and Henao, 2022). This energy is pollution-free, but costs two to three times more than normal and is limited in areas with tectonic activity. The Geothermal Atlas of Colombia highlights as areas of greatest potential the volcanoes Chiles-Cerro Negro, the Azufral volcano in the department of Nariño, the National Park of los Nevados and the Geothermal Area of Paipa-Iza Boyacá (Ponomarenko et al., 2022).

3. RESULTS AND DISCUSSION

More than 80% of the projects that are developed nationwide have as an energy source the photovoltaic or hydraulic solar, we find that 927 projects of the 1634 belong to the first category with 57%, of this first group of projects it is highlighted that 55% of the projects are located in the first phase, while, in the second phase we have 334 projects which symbolizes 36% of the projects of this type, the remaining 9% is located in the third phase with a total of 80 projects. On the other hand, the second source with the highest percentage in the territory is hydraulics, which has a total of 502 projects nationwide that represent 31% of the projects, in Figure 1 it can be evidenced that 348 projects of this type are in the first phase, maintaining the same trend as the previous source where we find that most of the projects are in this phase, in this order of ideas the other projects of this type are in the second and third phases, maintaining 125 projects and 29 projects respectively, these two phases represent 31% of the projects in this category. The other five sources analyzed in this research represent 12% of the projects at the national level, this can be evidenced in Figure 2, where we observe that the thermal, wind, offshore wind, biomass and geothermal energy generation projects have

Figure 1: Number of projects according to their phase (2007-2022)

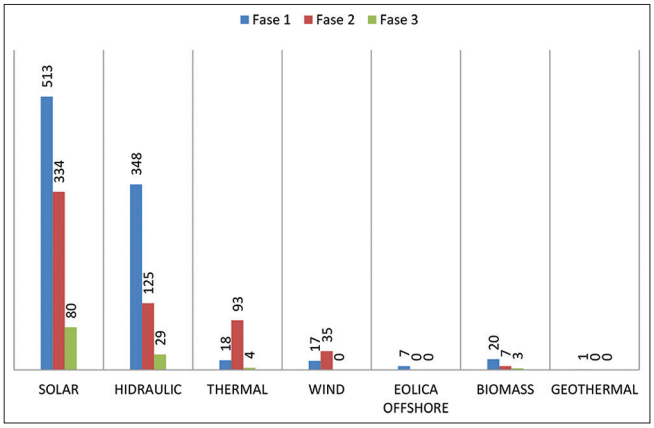
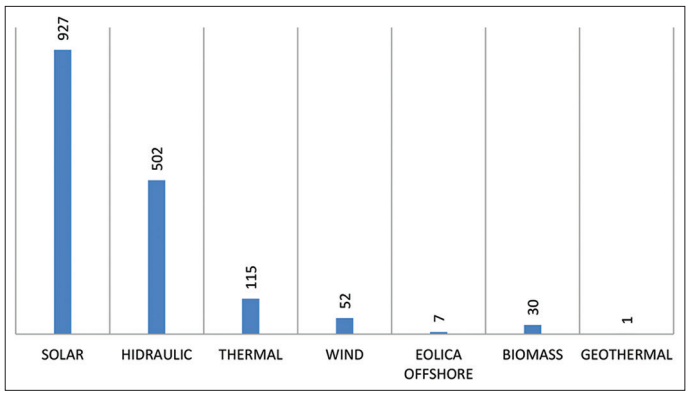


Figure 2: Number of projects accumulated according to their energy source (2007-2022)



115, 52, 7, 30 and 1 projects respectively, on the other hand, we observe that the trend of maintaining more projects in the first phase is maintained in three of the five categories, highlighting the offshore wind and geothermal sources which maintain 100% of their projects in phase one, likewise, the biomass source has 20 projects in this phase, which symbolizes 67%, on the other hand, phases two and three have a representation of 23% and 10% correspondingly. The thermal and wind energy projects break with the pattern, maintaining a greater number of projects in the second phase than in the first as do the rest of the energy sources, we observe that the thermal source has 18, 93 and 4 projects in phase one, two and three respectively, while the wind source has 17 and 35 projects in phase one and two in Figure 1 we can see that the last source mentioned does not maintain any project in phase three.

The energization projects have been classified according to their operating power, in Figure 3 it is evident that with 29.99% the projects between 0 and 1MW are those with the highest occupancy, followed by those between 1 and 10 MW with 25.03%, in third place, we have those between 10 and 20 MW with 18.48% and culminating with the projects categorized between 100MW, 50–100MW and 20–50MW with 11.75%, 9.55% and 5.20% respectively. It is important to mention that in all categories solar energy is the most widely implemented, evidencing the high interest and commitment to the development of this in the Colombian territory.

Until 2022 with the cut-off date of this research, 288 implementation projects with renewable energy sources were in force see Figure 4, of which solar energy leads with 75.35% of the implementation projects, hydraulic energy is in second place with 13.89%, in third place with 6.60% is wind energy, which has had a great awakening in recent years, closing this classification are offshore wind, thermal and finally the source of energy by biomass, each with 2.43%, 1.04% and 0.69% respectively. This shows that the Colombian territory is currently strongly committed to the development of energization with two sources of energy, solar photovoltaic and the already traditional hydraulic energy, however, the high increase in the implementation of wind energy stands out.

In total there are 287 projects categorized in phase 1 or phase 2, and one project to be categorized, 115 projects are in phase 1 and 172 are in phase 2 see Figure 5, within phase 1 the energies that lead are solar photovoltaic and hydraulic with 64.35% and 22.61%, while for phase 2, with 83.14% solar energy is the one who leads in this stage of the implementation process, see Figure 6. This same trend is replicated in the categorization of energization projects according to their source vs the power or implement, it turns out that the solar energy source leads each of the categories, being the one of May impact the one between 1 and 10MW with said energy source has 90 projects in execution, as shown in Figure 7.

Figure 3: Number of projects according to their power range (2007-2022)

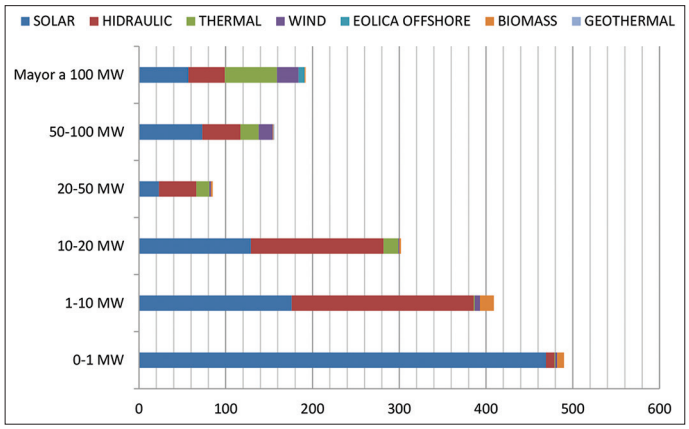
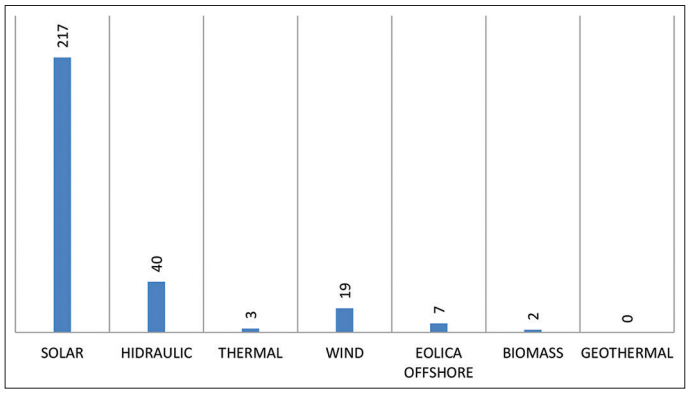


Figure 4: Number of current projects 2022 according to the energy source



Although the number of projects is important when it comes to energizing an area, what is really transcendental is the power that said project can develop, since this would be the direct impact on the number of population benefited, in Figure 7 it is evident that although the number of current projects is greater in the power range between 1 and 10MW, however, in Figures 5 and 8, it turns out that it is the power range >100MW where the greatest impact (energization coverage) of a beneficiary population would be obtained, this because the few projects that exist in this power range give a total of approximately 17000 MW which is equivalent to more than 50% of all the power generated between all power ranges.

To date cut off this research was an approximate total of 23000 MW in current projects, where 105111.33 MW corresponds to solar energy, 4835 MW corresponds to offshore wind energy, 3269.6 MW are equivalent to wind energy, 2830 MW of thermal energy, hydraulic energy has 1306.49 MW, 5.86 MW of energy by biomass see Figure 9, all these powers demonstrate the commitment of Colombian society and its leaders in diversifying the energy matrix and gradually eradicating the dependence on fossil fuels as a source of energy, thus demonstrating the fulfillment of the responsibilities acquired in international treaties and protocols, it is also a message to the countries of the region in achieving an alliance of regional interconnection and implementation of new renewable technologies as sources priority.

Figure 5: Number of projects in force 2022 according to their phase and power range

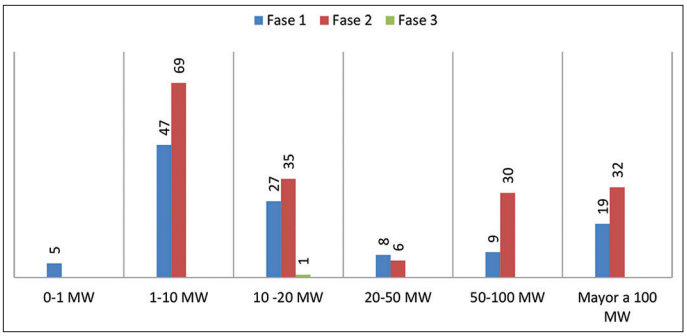


Figure 6: Number of current projects 2022 by phase

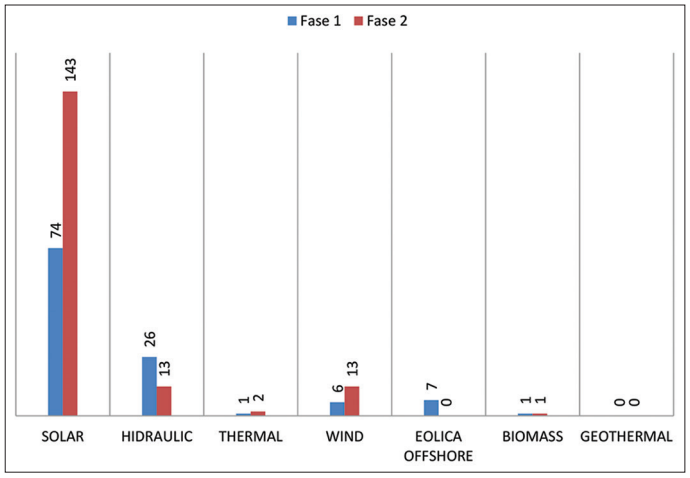


Figure 7: Number of projects in force 2022 according to their power range

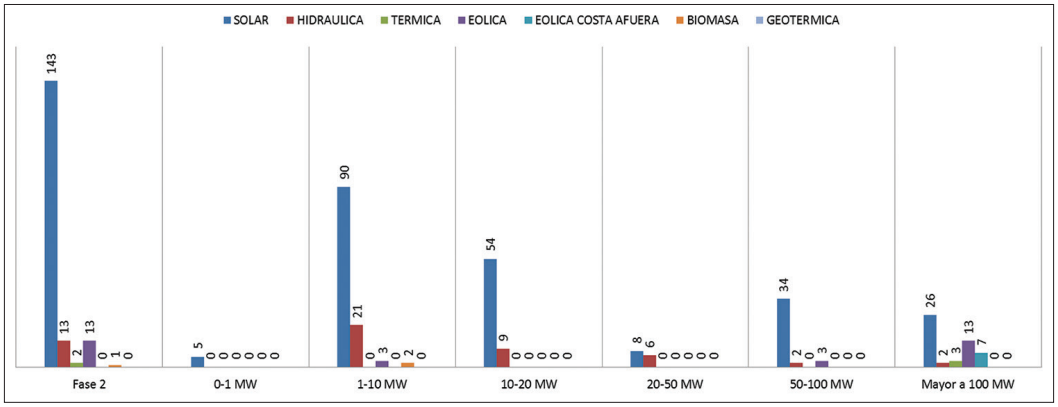


Figure 8: Cumulative of current projects according to power range

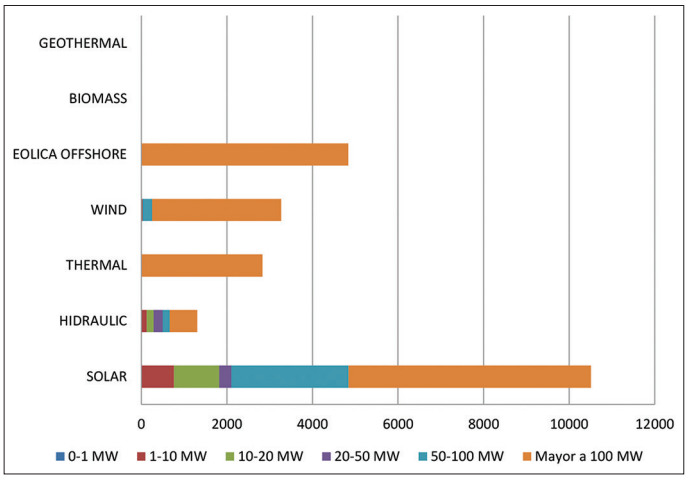
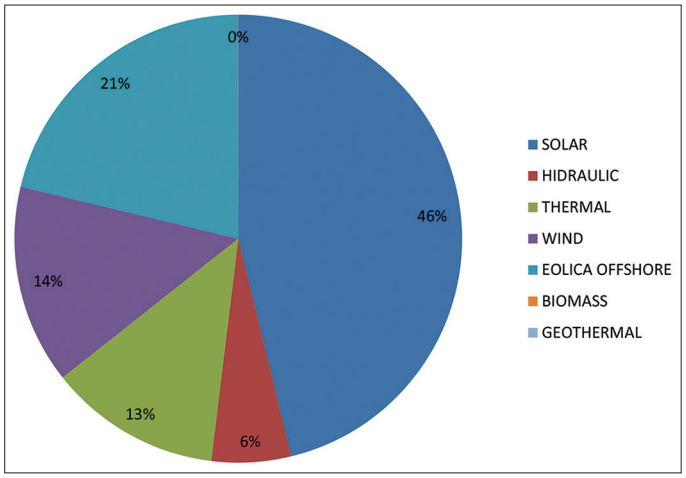


Figure 9: % of accumulated power 2022 of current projects according to energy source



The implementation of renewable energy projects must have a political endorsement and support, this is evidenced in the commitment of the last government to combat climate change in Colombia with the renewable energy law. Law 2099 of 2021 is modified and added to Law 1715 of 2014, the aim is to modernize current legislation and accelerate sustainable development through the adoption of new sources of non-conventional renewable energy generation, likewise, energy efficiency and sustainable mobility are sought, and thus reduce somewhat the great gap in access to non-conventional sources of energy.

3.1. Purposes of the Law

Focused on reducing the high dependence on energy from fossil fuels, what is wanted with this regulation is to incorporate new sources of non-conventional renewable energy, and as a consequence boost the market, as well as go permanently to them because they are inexhaustible since in their use they cause a very low affection to the environment and thus combat climate change, because they do not generate waste.

3.2. Main Guidelines of the Energy Modernization Law

In order to encourage the generation of electricity from non-conventional sources, FNCE, efficiently manage energy, promote research, development and investment in the field of its production, Law 2099 highlights the following aspects:

Extends tax and tariff incentives (Arts. 8, 9, 10 and 11).

It establishes that the national government will promote photovoltaic self-generation in official buildings, especially dedicated to the provision of educational and health services (art. 12).

3.3. Add the Concepts of Green and Blue Hydrogen (art. 5°)

It transforms the Non-Conventional Energies and Efficient Energy Management Fund (FENOGE), strengthening its role as a resource multiplier, market catalyst and enhancer of developers and implementers of energy efficiency solutions (art. 7°).

Geothermal energy will be considered as a non-conventional source of renewable energy, it will also evaluate the potential of geothermal energy, it will also create the geothermal registry where all those projects aimed at exploring and exploiting geothermal energy to generate electricity will be registered (arts. 13 and 14).

It points out the sanctions for those who carry out activities related to the development of electricity generation projects from the geothermal resource and incur in violation of the rules contained in this law and in the normative provisions and technical regulations

that regulate the activity of exploration and/or exploitation of geothermal resources for the generation of electrical energy (arts. 15 and 16).

It promotes the production and use of hydrogen, which states that the mechanisms, conditions and incentives must be defined to promote innovation, research, production, storage, distribution and use of hydrogen for the provision of the public service of electrical energy, energy storage, and decarbonization of sectors such as transport, industry, hydrocarbons (art. 21). The necessary regulations for the promotion and development of carbon capture, use and storage (CCUS) technologies will be developed (Art. 22).

The law also includes provisions for the public service of electric power in non-interconnected areas, ZNI; promotes the development of hybrid solutions that combine local sources of electricity generation, especially those that come from non-conventional energy sources, FNCE, for the provision of energy service for ZNIs. In the same way, it includes new measures for the concession of surface and/or groundwater that will be granted by the environmental authority in the environmental license, when applicable, depending on the type of use of the geothermal resource that is going to be advanced. It also incorporates incentives for electric mobility and points out that from the 3rd month of validity of the law, in order to promote the efficient use of electric energy in passenger mobility and promote the electrification of the economy, companies providing the urban public service of mass passenger transport will not be subject to the planned contributions, such as article 47 of Law 143 of 1994

4. CONCLUSION

This research has made it possible to identify the current situation in Colombia with respect to the use of renewable energy sources by analyzing the evolution that the use of different renewable sources has had, during the last 15 years. On the other hand, it is possible to identify the percentage of participation of the different leading sources in the current projects, highlighting solar and offshore wind energy as development potentials, also observing the participation of the different sources categorized according to their power range and implementation phase, where projects with more than 100 MW equivalent to more than 50% of the total registered in all current projects. The energy matrix that characterizes Colombia depends mainly on the behavior of the rains to achieve adequate water levels in the different reservoirs.

The phenomena known as El Niño or La Niña alter the level of rainfall and therefore affect the generation of electricity in the other hydroelectric power stations that the country has, therefore, in many cases, it is necessary that the power plants that were backed in an emergency or abnormal situation and work with fossil fuels. Faced with these scenarios, the introduction, development and implementation of renewable energy sources are beneficial. It should be noted that the electrical system has been evolving favorably in recent years, mainly due to the adequate provision of the private companies and the Colombian government to promote the BEEF, for example, the implementation of the Law 1715 of 2014 and updates, is looking to diversify the electricity matrix pointing to the inclusion of renewable sources through tax incentives for those who develop projects of self-generation and surplus sales.

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