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Study on the Applicability of Sustainable Development Policies in Electricity Generation Systems in Colombia

Luis Obregon[1], Guillermo Valencia[2], Jorge Duarte[2]*

[1]Grupo de Investigación Procesos Químicos y Bioquímicos Sostenibles, Departamento de Ingeniería Química, Universidad del Atlántico, Puerto Colombia Área Metropolitana de Barranquilla - 081007, (Atlántico) Colombia, [2]Grupo de Investigación KAÍ, Departamento de Ingeniería Mecánica, Universidad del Atlántico, Puerto Colombia Área Metropolitana de Barranquilla - 081007, (Atlántico) Colombia. *Email: jorgeduarte@mail.uniatlantico.edu.co

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ABSTRACT

This study investigates the current situation of electricity generation from renewable energy sources in Colombia and the energy situation of the Colombian population. In general, it was demonstrated that Colombia has potential in renewable sources, mainly in solar energy, wind, and biomass. However, technical, economic and social barriers such as the lack of human capital, policies focusing on conventional technologies, high investment costs, as well as technological limitations due to the instability, intermittency and low efficiency inherent in renewable energy sources, have impeded their development. Despite the promotion of these renewable sources through Law 1715, greater commitments are needed to implement and improve energy policies, as well as investments in precise research on Colombia's energy potential and new existing technologies. For the technological limitations, this study proposes the use of energy storage systems, by means of battery systems or the use of biomasses such as chicken feather fibers and the peel of the oil palm for the production, storage and use of hydrogen as an energy gas. It was done to eliminate the instability and intermittency of renewable energy sources. Additionally, the advantages of thermoelectric devices are presented, which, coupled to photovoltaic cells allow increases of 2-10% in the efficiency of solar panels. In addition, the features of these devices let to generate electricity from the waste heat of virtually any process. This quality could increase in industrial sectors in Colombia such as the steel industry, the ceramics sector, the cement industry, and in the recovery of heat from the exhaust gases of diesel generators. The latter is used mainly in non-interconnected zones. This is intended to improve the efficiency of the processes, as well as the reduction of fuels in the case of diesel generators.

Keywords: Renewable Energies, Energy Storage, Hydrogen, Thermoelectric Devices
JEL Classifications: O13, O38, Q42

1. INTRODUCTION

Energy is a very important factor in the development of a country, as it is fundamental for the industrial and economic growth of any society. Whether for employment, security, food production, or income growth, access to energy is indispensable. However, electricity production together with other sectors such as industry, agriculture, and transport together account for more than 80% of anthropogenic greenhouse gas emissions causing climate change, which is one of the main environmental problems of modern society (Meyer and Pachauri, 2015). Due to this situation, the massive implementation of renewable energy sources for electricity generation has been considered as the main strategy (Resch et al., 2014).

On September 25, 2015, the United Nations (UN) adopted the 2030 agenda on sustainable development. Seventeen sustainable development goals were presented in this agenda in order to meet the needs of the present without compromising the ability of future generations to meet their own needs. Among these objectives is objective 7: To guarantee access to affordable, safe, sustainable, and modern energy for all (Figure 1).

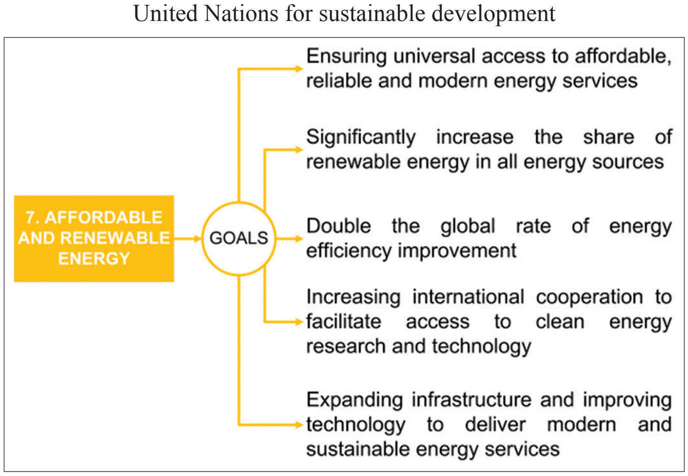
The goals of this objective are of special importance because it directly affects the development of other objectives. Improving energy and increasing the use of renewable sources is vital for creating more sustainable and inclusive communities and helping to reduce environmental problems such as climate change. In spite of the advances in the field of sustainable energy, there is still no universal development to reach the goals of the analyzed objective. The use of renewable energy should continue to be encouraged so that it reaches a much wider scale.

Colombia is one of the main growing economies in Latin America, leading to growing energy demand. The country's main energy source is hydropower, combined with fossil fuel sources (UPME, 2015). However, climatic phenomena such as "El Niño" and "La Niña" cause a decrease in hydropower, which increases the consumption of fossil fuels to provide the demanded electricity supply. Mainly in non-interconnected areas of the country, where the main sources of energy are through diesel generators and small hydropower, which leads to increased levels of pollution.

Through institutional laws such as Law 1715 of 2014, it seeks to promote and develop renewable energy technologies such as solar photovoltaic, wind, small hydro, geothermal, and biomass, among others. With the objective of satisfying the country's growing demand for electricity and improving electricity service in the country's non-interconnected areas. However, despite this law, there are still different technological barriers, such as low energy conversion efficiency, intermittency, and instability of this type of energy sources, which limit its implementation.

This document shows the potential of different types of renewable energy sources available in Colombia, the limitations of Law 1715 in reaching its objective, different technological strategies for better use of renewable energy to encourage its use, mainly in non-interconnected areas of the country, as well as alternatives to reduce the consumption of fossil fuels in Colombia. The above was done to promote the participation of Colombia in the objectives of sustainable development proposed by the UN, mainly in the objective of to guarantee access to affordable, safe, sustainable and modern energy for all.

Figure 1: Goals of the seventh objective proposed at the United Nations for sustainable development



Source of data: Prepared by the authors based on data from (Morán, 2019)

2. ENERGY SITUATION IN COLOMBIA

2.1. Energy Demands

According to reports from the Energy and Mining Planning Unit (UPME, for its abbreviation in Spanish) the consumption of primary energy in Colombia has increased more than 200% in recent decades. In 1980 it generated 205, 150 GWh while in 2012, the generation was 454, 260 GWh (UPME, 2015). In 2018, demand in the entire Colombian territory grew by 3.3% (S.A.S., 2019).

Due to the economic growth of the country, the demand for energy will tend to increase. According to the mining and energy planning unit (UPME), demand is projected to grow at an average rate of 3.4% (Congress of Colombia, 2000). Therefore, the environmental problems caused by power generation from conventional sources and the depletion of natural resources lead to the need to increase the use of alternative generation sources.

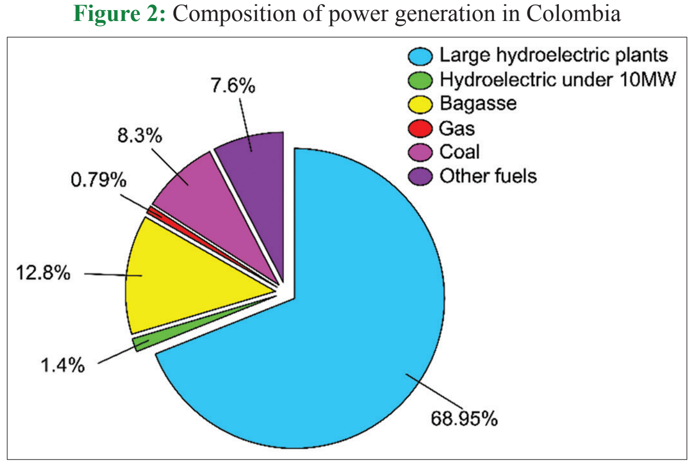
2.2. Generation of Energy

The energy sector in Colombia is mostly generated through hydroelectric plants, which is equivalent to 68.9%. The rest comes from thermal plants and only 0.7% from non-conventional renewable energy sources (UPME, 2018). Figure 2 shows the installed capacity for electricity generation in Colombia.

Due to its high dependence on water resources, Colombia is affected by meteorological phenomena such as "El Niño" and "La Niña." Figure 3 shows the behavior of energy generation by primary energy sources between 2007 and 2016. The fluctuations in the periods 2009-2011 and 2014-2016 are the result of meteorological events (González et al., 2017).

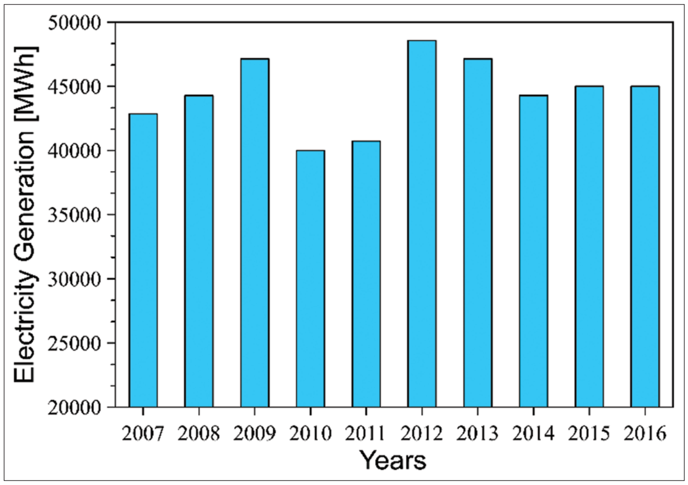
Studies indicate that this type of fluctuation tends to increase due to climate change (CORPOEMA, 2010). This forces thermal

Figure 2: Composition of power generation in Colombia



Source of data: Prepared by the authors based on data from (UPME, 2017; XM, 2018)

Figure 3: Generation of electricity from the primary sources of Colombia



Source of data: Prepared by the authors based on data from (UPME, 2017)

power plants to support these variations in hydropower production, leading to an increase in pollutant emissions (UPME, 2015).

2.3. Social Situation

Colombia currently has 48,747,632 inhabitants located in 32 departments (DANE, 2017). In terms of energy, it is divided into two zones (Figure 4).

Interconnected areas, which have access to electricity service through the National Interconnected System (SIN, for its abbreviation in Spanish), which connects 48% of the national territory and serves 97% of the population (Vides et al., 2017).

Non-interconnected zones (ZNI, for its abbreviation in Spanish), according to article 1 of Law 855 of 2003 are municipalities, districts, localities and villages that are not connected to the SIN, due to their locations in remote and inaccessible sites (Gaona et al., 2015). The ZNI represents 52% of the country's area (Figure 4). The main source of electricity production in these areas is Diesel generators (García et al., 2013).

It is important to mention that more than 40% of the population does not have good quality service or constant electricity, only receives four hours of energy service per day mainly from Diesel silver (98%) and a low percentage of renewable energy (1.2%) (Rodríguez and Rodríguez, 2018).

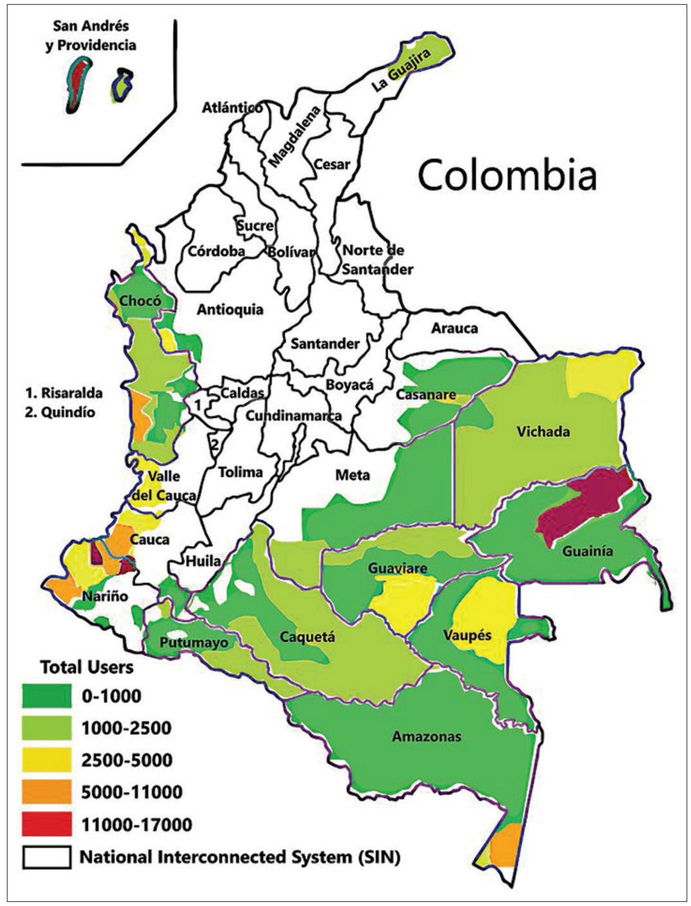
2.4. Renewable Energy Policies

In Colombia, there are public institutions with direct responsibilities in the promotion of alternative energies. The names of these institutions and their responsibilities are shown in Figure 5.

These organizations work on policies and incentives for the multiplication of successful experiences in the field of clean energy.

Due to the need to diversify energy sources in Colombia and to improve access to electricity in non-interconnected areas,

Figure 4: Energy zones in Colombia (location of ZNI and SIN)



Source of data: Prepared by the authors based on data from: (Rodriguez and Rodriguez, 2018)

Law 1715 of 2014 was established. This law promotes the development and use of non-conventional energy sources, mainly from renewable sources, through investment incentives in non-conventional energy sources (FNCE, for its abbreviation in Spanish) projects in ZNI, tax incentives, income tax deduction, Value Added Tax (IVA) exemption for goods and services used in the development of FNCE projects, tariff incentives (exemption from customs duties when importing machinery and equipment to be used in the development of new FNCE projects) and accounting incentives (accelerated depreciation of assets).

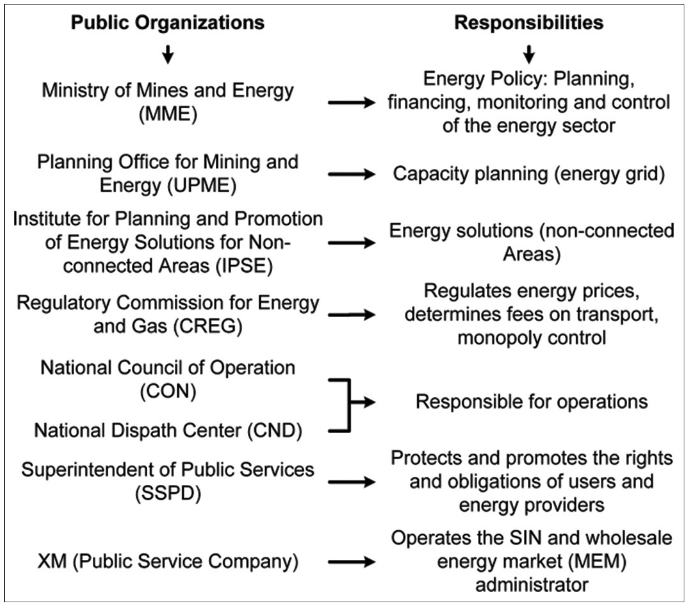
3. RENEWABLE ENERGY SOURCES

Colombia has several renewable energy sources with great potential to enter the electricity market. According to literary reviews, photovoltaic, wind, biomass, small hydroelectric, and geothermal power plants are the main sources of renewable energy (UPME, 2015; Radomes and Arango, 2015). However, Colombia has the capacity to exploit other types of sources, such as tidal and wave energy and ocean thermal energy (UPME, 2013; UPME, 2015; CORPOEMA, 2010a).

3.1. Solar Energy

Figure 6 shows the installed photovoltaic capacity (kWp) in each department of Colombia.

Figure 5: Responsibilities of public institutions in the energy sector



Source of data: Prepared by the authors based on data from: (Edsand, 2017)

Because Colombia is located in the equatorial zone, it has constant solar radiation in certain areas of its territory. In the whole territory, it presents an average of 4.5 $KWh/m^2/day$, which is one of the highest radiation indexes registered worldwide, compared to countries such as Africa (Gómez and Ribó, 2018). Despite this high solar energy potential, <3% of the energy consumed comes from the solar source.

Figure 6 shows a development mainly in the central area of the country, the Atlantic coastal zone, and the Pacific sector. However, in the department of La Guajira, which has the highest national radiation (5.5-6 kWh/m^2), there is low development in solar technology.

Despite this energy potential, technical barriers such as the low conversion efficiency of photovoltaic cells have reduced the development of the photovoltaic sector.

3.2. Wind Energy

3.2.1. Terrestrial wind energy

Colombia is qualified as one of the best countries in South America to generate electricity through wind energy. the Guajira in northern Colombia, for example, has some of the best wind potentials in South America. The winds in this region of the country blow almost all year round, with an average wind speed of 9.8 m/s. Other regions of the country, including the island groups of San Andrés and Providencia, along with the departments of Santander, Norte de Santander, Boyacá, Valle del Cauca, Risaralda and Huila also have the potential for wind energy (Edsand, 2017).

On average, Colombia has a coastal wind presence of 9 m/s at a height of 50 m. Only by using half of its total wind technical potential, Colombia could satisfy the electricity demand of the entire country. In addition, it has been demonstrated that wind energy serves as a good source of energy complementary to existing hydroelectric generation. Higher average wind speeds

Figure 6: Solar energy projects in non-interconnected zones (ZNI) and national interconnected system (SIN) by the department

Source of data: Taken from: (Rodríguez and Rodríguez, 2018)

have been found to coincide with droughts caused by El Niño, a period in which the capacity of hydroelectric plants decreases. The development of wind energy could guarantee a reliable energy supply in Colombia.

3.2.2. Marine wind energy

Maritime wind energy has certain advantages when compared to terrestrial energy. One is that in the ocean, wind speed is higher and less unstable due to the lower roughness of the sea surface. Moreover, being located in the sea, this type of energy does not have the barrier of rejection by indigenous peoples, this being one of the factors that have limited the progress of wind energy on land.

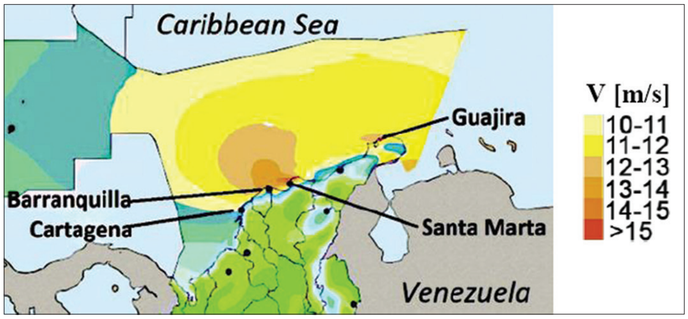
Estimates show that Colombia has a high potential in marine wind energy. Figure 7 shows the distribution of wind speed on the Caribbean coast.

According to studies, areas such as La Guajira (482 W/m^2, at 110.8 m), Barranquilla (857 W/m^2, at 323.2 m) and Santa Marta (658 W/m^2, at 10 m) have the same level of energetic potential as the best terrestrial wind areas of La Guajira.

3.3. Biomass

Colombia's agricultural sector is a potential source of biomass. There are several residual materials such as sugar bagasse and

Figure 7: Distribution of the average annual wind speed (m/s) on the coast of Colombia



Source of data: Prepared by the authors based on data from: (Rueda et al., 2019)

panela, rice cascarilla, coconut fiber, coffee pulp, oil palm, sugar cane, and barley. According to UPME reports, 29 million tons/year of residual biomass are reported, with an energy potential of 12 MWh/year. In addition, the country has other sources of biomass, such as algae production, livestock production systems, which generate large volumes of manure (Castillo et al., 2015).

In Colombia, electricity generated by biomass sources represented about 804 GWh, equivalent to 1. 3% of electricity generated in 2013. Mainly due to the use of sugar cane bagasse (UNIDO, 2013). Research shows that installed biomass capacity in Colombia could be up to 15 GW, mainly in non-interconnected areas where much of the biomass is produced.

3.4. Ocean Thermal Energy

Colombia's geographical location, surrounded by the warm tropical waters of the Caribbean Sea and the Pacific Ocean, allows the country to be an adequate territory for the conversion of oceanic thermal energy (OTEC). Different investigations show that the temperature gradient, bathymetric, environmental and socioeconomic characteristics present in the maritime area around the island of San Andres (in the northwestern Caribbean Sea) is ideal for an OTEC installation, since the sea surface temperature varies slightly (Morales et al., 2014; Mendoza et al., 2019). Observations show that the thermal difference found from the surface to a depth of 1000 m is always around 22-24°C and cold water is available for use at a depth of approximately 450-470 m, at a horizontal distance from the coast of <2.5 km. At these depths, the thermal gradient of 20°C required for OTEC operations is achieved. In addition, the winds, waves, and surface currents around the island are of relatively weak intensity (Morales et al., 2014).

4. OBSTACLES TO THE DEVELOPMENT OF RENEWABLE ENERGY SOURCES IN COLOMBIA

If renewable energy sources were promoted in Colombia, electricity production would be almost 100% renewable since it is based on hydroelectric energy (UPME, 2015). However, despite laws such as 1715, there has not been a high level of development in renewable energy sources.

We can classify the barriers that hinder energy sources in Colombia in three main categories: technical, economic, and social barriers.

4.1. Technical Barriers

Although it is not necessary to pay customs duties when importing equipment for the use of energy source projects, these tax reductions often do not apply to these materials, as customs officials do not have an established criterion for differentiating materials. Because of this, you usually have to pay taxes or file claims that cause delays (Ahlborg and Hammar, 2014).

In addition to this, there is a need for more accurate data on the capacity of geothermal, meteorological, and renewable resources. This lack of data leads to increased risks and costs for investors (García et al., 2013).

4.2. Economic Barriers

Normally ZNI zones have subsidies for electricity generation. These subsidies are based on receiving diesel engines from the government, as it is considered a reliable form of electricity generation. Due to this, resources are reduced that could be invested in the use of energy sources in these areas, which tend to have great renewable potential and high environmental value (Gaona et al., 2015).

One of the main drawbacks of the energy sector in Colombia is that the price of electricity is determined by the spot market. Therefore, each MWh is paid regardless of the type of generation technology or geographic location. This implies a great disadvantage for renewable energy sources since they have to compete on equal terms with conventional energies, such as coal, gas, and hydroelectric energy (Gómez and Ribó, 2018).

In addition, renewable energy projects tend to be smaller compared to traditional power plants. They are, therefore, less able to trade with the main consumers (Bastidas et al., 2013).

4.3. Social Barriers

The ministry responsible for electricity and renewable energy in Colombia makes decisions, issues standards, and plans for the development of renewable technologies. However, they often act independently of the interests of stakeholders such as private companies, non-profit organizations, investors, or local communities.

This is compounded by insecurity in rural areas, especially in the event of armed conflict, which leads to the abandonment of the project.

5. STRATEGIES FOR THE DEVELOPMENT OF RENEWABLE ENERGIES IN COLOMBIA

5.1. Energy Storage

Despite the energy potential of renewable energy sources in Colombia, no integration of these energies into the electricity grid has been achieved. Solar energy and wind power are the most efficient and well-known sources in Colombia. However, the main disadvantage of this type of energy is intermittence and instability, due to its nature dependent on atmospheric conditions (Chen et al., 2017).

In order to solve this problem, the use of energy storage systems, together with renewable energy sources, has been investigated (Worighi et al., 2019).

5.1.1. Energy storage in batteries

Battery storage technology has been shown to be a satisfactory way to meet energy storage demand (Akinyele and Rayudu, 2014). Battery storage technology is found both on an industrial scale and in domestic battery systems. Battery power storage has a fast response time, design flexibility, according to demand, provides voltage regulation, power frequency regulation, load leveling, quality control, and reliability (Lehtola and Zahedi, 2019).

In non-interconnected zones, electricity is normally produced by means of diesel generators. Dependence on diesel fuel, the transport of diesel fuel, its often-low load operation (leading to low efficiency), are the main drawbacks of using diesel generators.

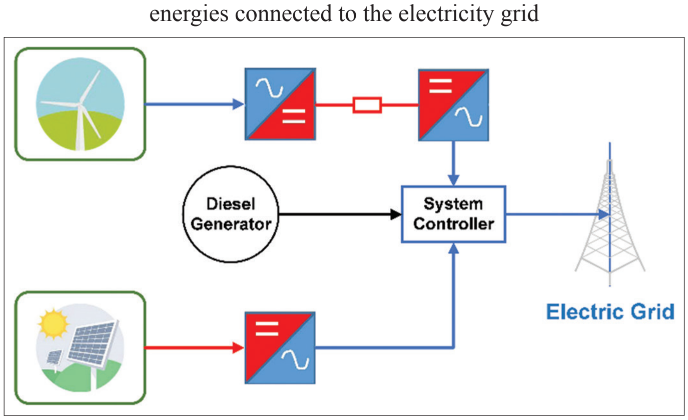
In order to reduce dependence on diesel fuel, systems such as V_2G (vehicle-to-grid) storage in parallel with battery storage have been investigated. Figure 8 shows the system made up of renewable energy resources (solar and wind) and a diesel generator. The system allows the integration of solar and wind energy for power generation in remote zones.

The system is shown (Figure 8) allows excess energy from solar and wind sources to be stored in EV batteries operated by V_2G operations. Generators operate at a higher load level, providing more efficient power generation. Battery chargers charge batteries during electrical charging during peak hours and release batteries when renewable resources cannot meet demand. When battery power generation is weak, the Diesel generator provides electricity.

5.1.2. Hydrogen energy storage

The main drawback of the system shown above is the high cost and relatively short life of EV batteries. An alternative is hydrogen storage systems (Lehtola and Zahedi, 2015).

Figure 8: The configuration of the diesel generator and the renewable energies connected to the electricity grid



Source of data: Prepared by the authors based on data from: (Lehtola and Zahedi, 2019)

Hydrogen is considered a potential source of energy (Kaur and Pal, 2019). Hydrogen has several advantages, such as its high specific energy, compared to other fuels, for example, the energy content of 9.5 kg of hydrogen and 25 kg of gasoline is equivalent (Das, 1996), is the lightest element and can be easily transported and stored in different ways.

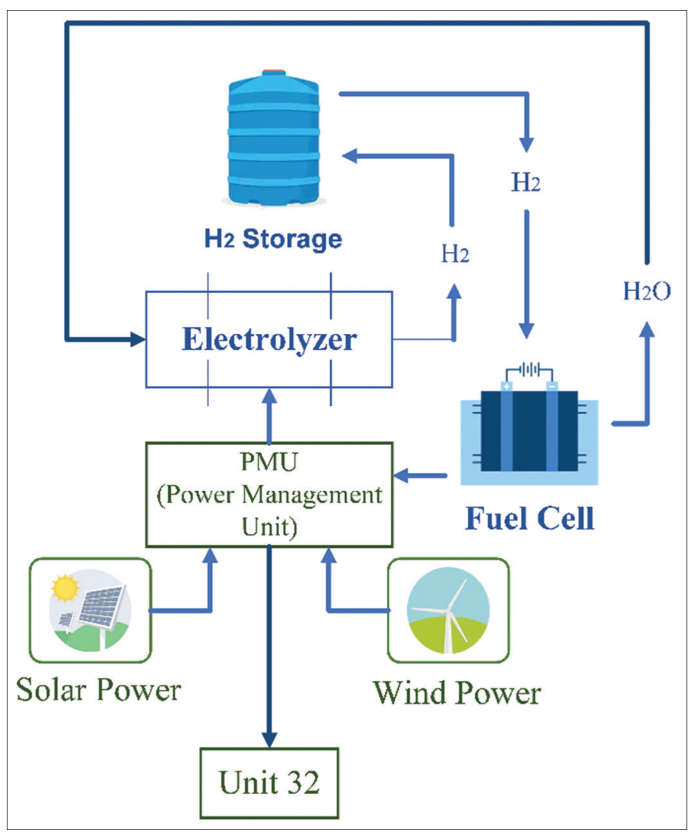
Hydrogen storage systems can be an option to overcome battery costs and eliminate fluctuations and intermittences from renewable energy sources. Figure 9 shows a schematic of a hybrid photovoltaic/wind energy system with hydrogen storage.

In unit 32, energies are supplied from photovoltaic and wind power sources. When these sources are not available, power will be supplied by the storage system. If the total energy produced by the renewable energy sources is greater than the unit's energy demand, the electrolyzer uses the excess electrical energy to produce hydrogen and store it in hydrogen tanks. This type of scheme agrees with different studies on renewable hybrid energy systems with hydrogen storage system (Khosravi et al., 2018).

The main disadvantage of this type of system is the costs incurred for hydrogen storage. However, Colombia has potential biomass resources that can be used as hydrogen storage materials.

Chicken feather fibers from Colombia's poultry industry may be a potential ecological and bio-renewable candidate, with a characteristic similar to carbon nanotubes (Carbon nanotubes structures can retain large amounts of hydrogen at normal pressure,

Figure 9: Schematic of the hybrid renewable energy with the hydrogen storage system



and in small spaces, however, its high manufacturing cost makes it an unsustainable process). Research on the hydrogen storage capacity of chicken feather rachis has shown that, through heat treatment processes, the chicken feather rachis reaches a maximum capacity of 3. 5% by weight, which is a very attractive result due to the low cost of the material (Giraldo and Moreno, 2013).

The peel of the oil palm is a by-product of the African production of oil palm. Colombia produces annually about 3 million tons/year. Due to its great volume of availability and low cost, has attracted attention as a material for energy use. Several investigations have reported on the production of activated carbons from by-products of the African palm oil as hydrogen storage material (Hameed and El-Khaiary, 2008).

Gonzales et al. (González et al., 2014) developed a chemical activation process with LIOH and a modified commercial microwave oven to obtain an adequate porous structure in the palm shell of oil for hydrogen storage. From this process, a maximum storage capacity of 6. 5% was obtained. Therefore, the shell of the oil palm becomes a material with potential for hydrogen storage.

5.2. Thermoelectric Devices

Thermoelectric devices (TE) have emerged as an important source of renewable energy. TE devices consist of a series of thermocouples formed by a material type p and type n, which are connected electrically in series and thermally in parallel (Figure 10).

TE devices can be used for cooling (converts electrical energy into heat by the Peltier effect) and for heat generation (converts heat into electrical energy directly by the Seebeck effect). The advantages of TE devices are numerous: they allow the direct conversion of thermal energy to electrical energy or vice versa, have no moving parts or internal fluids, thus requiring no maintenance, long service life, scalable technology and quiet operation (Li et al., 2018).

The features and advantages of TE devices allow them to be applied in a wide range of situations. Among the main situations, we can mention Electricity generation through solar energy, decentralized domestic energy, and recovery of residual heat (Champier, 2017).

5.2.1. Thermoelectric devices for the improvement of photovoltaic energy

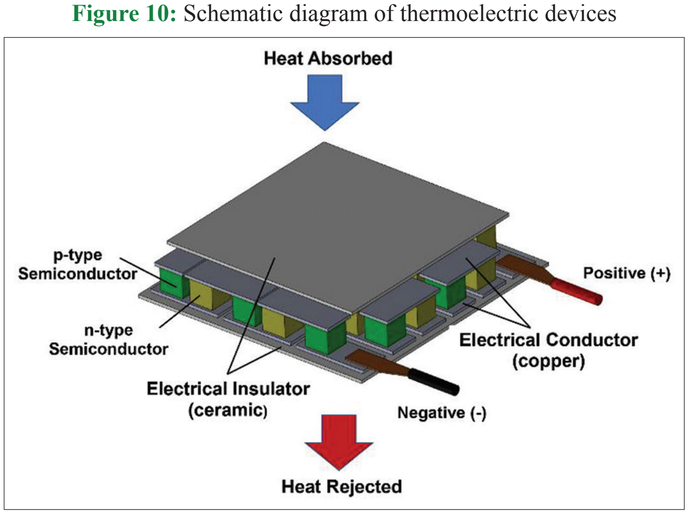
Photovoltaic solar energy is one of the main methods for the recovery of solar energy. However, photovoltaic cells convert only 10-15% of solar radiation into electricity, the remaining percentage is lost to the environment in the form of heat, and another part is absorbed by the photovoltaic cells, which increases their operating temperature, which decreases their conversion efficiency (Dimri et al., 2017).

Due to the tendency of photovoltaic cells to heat up, cooling is of paramount importance to improve system performance. It has been observed that even an increase of 1°C, the efficiency of photovoltaic cells decreases in a range of 0. 25-0.5% (Grubisic et al., 2016). Therefore, even a slight decrease in the temperature in the cells can significantly increase the efficiency of the system. Due to the above situation, different cooling techniques have been investigated in photovoltaic systems. Among the most applied and mature techniques are air and liquid cooling (Makki et al., 2015). However, alternative cooling techniques are still being investigated. These include the use of thermoelectric devices.

The use of TE devices in photovoltaic cells results in a water device with superior performance. Because TE devices and photovoltaic cells have complementary characteristics, the TE device can provide two functions: cooling the photovoltaic cells and producing additional energy.

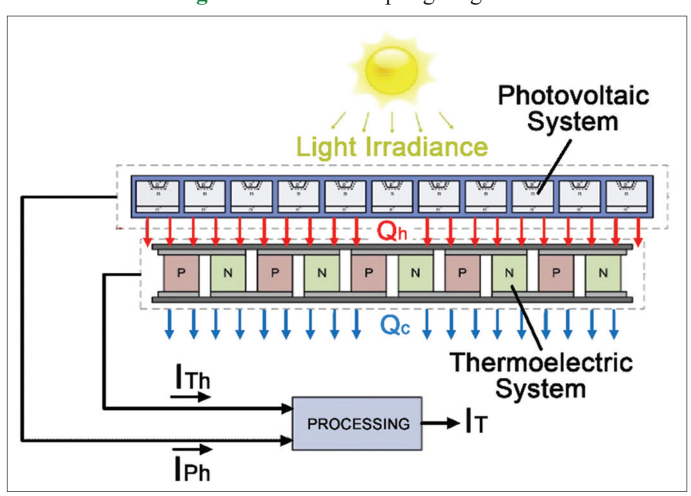
One of the main methods of integration between photovoltaic cells and TE devices is direct coupling. In this method, both devices are directly coupled and placed in a parallel arrangement. The photovoltaic cells are placed on top of the TE devices. Thus the solar radiation not absorbed by the cells is transmitted to the TE devices. This flow of heat into the TE devices allows them to generate electrical energy. Figure 11 shows a diagram of direct coupling.

Figure 10: Schematic diagram of thermoelectric devices



Source of data: Prepared by the authors based on data from (Li et al., 2019)

Figure 11: Direct coupling diagram



Source of data: Prepared by the authors based on data from: (Fisac et al., 2014).

The integration of TE devices in solar panels could provide an increase in the energy generated of 2 to 10% depending on the thermoelectric material, connection, and configuration (Babu and Ponnambalam, 2017).

Therefore, research into this type of system has increased due to its enormous potential to provide higher performance compared to conventional photovoltaic systems.

5.2.2. Decentralized household energy

As mentioned above, many territorial areas of Colombia are not electrified. The combination of low energy requirements and the low income of the population in isolated areas makes a connection to the electricity grid impossible.

In these remote area's biomass is one of the main means of energy, among these, is wood. In isolated areas wood is burned with very low efficiency (only 10% for places with fire and stone). In addition, the fumes are highly toxic (Anozie et al., 2007). According to the International Health Organization, the use of wood and waste for cooking and heating causes 400,000 premature deaths a year in India, mostly women, and children. The installation of efficient wood-burning stoves is essential for health and safety. However, these efficient stoves require the use of exhaust fumes to improve combustion. Electricity is, therefore, necessary both for the stoves and for the basic needs of the inhabitants.

TE devices are a solution to provide some watts for lighting or to charge mobile phones and electric power extractors for this type of stoves.

5.2.3. Waste heat recovery by thermoelectric devices

5.2.3.1. Industrial sector

The industry is a field where heat is normally a by-product of the process. Most of the time, this heat is wasted by being released into the atmosphere. In order to recover waste heat, several projects have been carried out using TE devices.

(Aranguren et al., 2014) have conducted experimental research and mathematical studies on a TE device for the recovery of waste heat from a combustion chamber. They concluded that their prototype has a potential production of 100 W/m^2. This result was extended to a large industrial stack in a ceramic tile kiln that has a flue gas mass flow of 18,400 Nm^3/h and a temperature of 187°C. The planned annual electricity production was estimated at 136 MWh/year.

The steel industry is an industrial sector that produces a large amount of waste heat, mainly from the radiant heat of steel products. TE devices are good candidates for recovering radiant heat from molten metal. In Japan, a system of thermoelectric devices has been implemented using radiant heat from continuous casting slabs (Kuroki et al., 2015). This system is connected to the grid and generates about 9 kW when the slab temperature is approximately 915°C.

Cement production is another industrial process with high heat losses and high energy consumption. (Luo et al. 2015) have studied the possibility of integrating TE devices into cement manufacturing. They estimated that approximately 10-15% of the energy is dissipated directly to the atmosphere through the outer surface of the rotary kiln. This type of lost heat is difficult to recover due to the permanent movement of the furnace. Through the development of a mathematical model, it was predicted that the inclusion of TE devices could produce 210 kW and save 3280 kW due to the insulation cover. The contribution of thermoelectric generation is approximately 2%.

Previous industry studies show that TE devices have two major advantages in the industry: heat recovery where other conventional methods would be difficult to implement and their ability to operate without maintenance. In this way, it is possible to obtain electrical energy at a low cost.

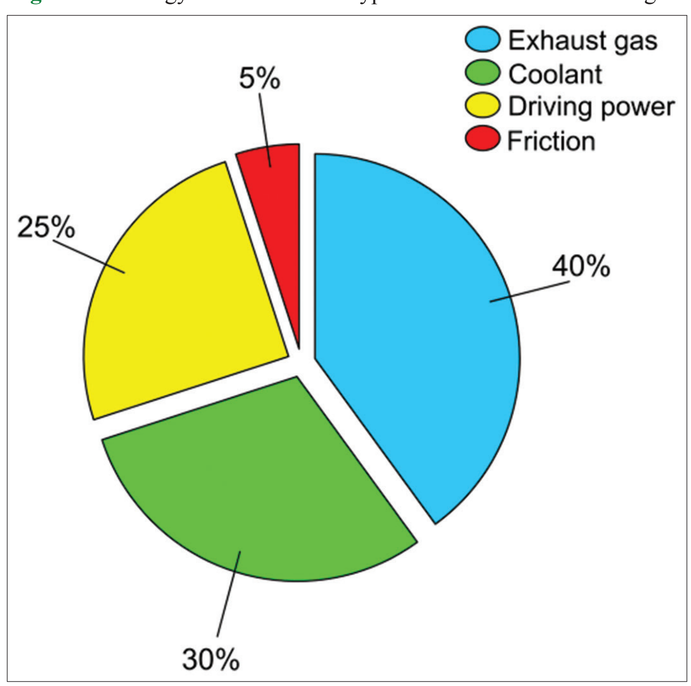
5.2.3.2. Diesel generators

Diesel generators are commonly used in non-interconnected areas as a power source. For a typical internal combustion engine on average, only 25% of the fuel energy is converted to mechanical energy. Approximately 5% is dissipated by friction; the remaining 70% is wasted in the form of heat, taken up by exhaust gases and engine coolant (Figure 12). Consequently, waste heat recovery is of critical importance for energy savings and reduction of pollutant emissions.

(Vázquez et al. 2002) estimate that fuel consumption could be reduced by about 10%, and consequently, 2×10^{10} kg of fuel could be saved and 6.2×10^{10} kg of CO_2 could be reduced annually for China if 6% of the exhaust heat is converted into electrical energy. This demonstrates the importance of energy recovery from internal combustion engines.

Of the different power generation technologies, thermoelectric devices have attracted attention due to their absence of moving

Figure 12: Energy distribution in a typical internal combustion engine



Source of data: Prepared by the authors based on data from: (Shen et al., 2019) parts, low maintenance cost, and high reliability. Therefore, in recent years, different researches have been developed that demonstrate the potential of TE devices as a means of generating electrical energy and reducing pollutant emissions from engines through fuel savings. (Niu et al., 2014; Negash, 2017; Vale et al., 2017).

6. CONCLUSIONS

Due to its geographical location and climatic conditions, Colombia possesses a great variety of natural resources for the generation of renewable energy. These include solar, terrestrial and marine wind, biomass, geothermal, and ocean energy.

Despite the creation of new regulations and laws promoting the use and development of clean, renewable energy sources, different technical, economic and social barriers, coupled with technological difficulties such as the intermittent, unstable and low efficiency inherent in the nature of energy sources, have slowed their development.

As a solution to the above-mentioned barriers, it is recommended:
- Train customs agents to ensure tariff exemptions for imported materials destined for renewable energy projects
- Promote collaboration between universities, research centers, and private companies to carry out better research that accurately shows Colombia's energy potential and the study of new technologies that favor the development of renewable energy sources
- Change subsidies from diesel generators to renewable energy sources in the ZNI. This would help promote the transition to the renewable generation
- Propose mechanisms of participation where the public and private sectors can make decisions together
- Implement tariffs that favorable electricity produced by renewable energy sources to offset their higher generation costs.

With regard to the technological difficulties mentioned above, it has been investigated that energy storage mechanisms such as battery coupling and the use of V_2G systems allow solar and wind energy sources to work together with Diesel generators. In this way, the instability and intermittency of these energy sources can be eliminated, and the use of fossil fuels reduced. Similarly, the hydrogen storage capacities of biomasses such as Chicken feather fibers and the peel of the oil palm can be used for completely clean electricity generation through hydrogen and with the ability to connect directly to the electricity grid.

In addition, the contribution that thermoelectric devices could make to the Colombian energy sector was investigated. Research shows that these devices, together with photovoltaic cells, can significantly increase the energy conversion efficiency of the cells. Increases from 2 to 10% are recorded. Another contribution of thermoelectric devices is their ability to produce electricity through waste heat. This could be exploited in various Colombian sectors such as the steel, ceramics, and cement industries, characterized by high rates of heat loss to the atmosphere. Finally, this capacity could be used in the diesel generators used mainly in the ZNI, to recover part of the energy wasted to the environment by the engine exhaust gases. In addition to that, use will reduce fuel consumption by up to 10%, as some research indicates.

All these recommendations and alternatives would improve the development and technological limitations of renewable energy sources in Colombia, mainly solar and wind energy, which have the greatest potential for recovery and the most advanced technology. Similarly, the use of residual heat is sought, and the reduction of fossil fuels.

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