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Article

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Overview of Potential Use of Hydroxyl and Hydrogen as an Alternative Fuel in Colombia

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ABSTRACT

In the Paris agreement about climate change, it was established that greenhouse gas emissions must be reduced by 0% in order to avoid irreversible damage, so the world economy based on fossil fuels must undergo a transformation towards an economy clean, safe and sustainable. As a result, it has been established that the only alternative that guarantees 0% emissions of polluting gases is the economy of hydrogen. Countries such as the Netherlands, the United States, and the European Union have projected policy towards 2050 that expects to meet the objectives set out in the Paris agreement. In this document shows the different alternative fuels that are currently being proposed to mitigate polluting emissions, as well as the overview of these fuels in Colombia, and how, from the different renewable energy sources that this country has, could venture economically and politically towards economy based on the use of hydroxy and hydrogen as a raw material and energy source, showing its possible applications. The foregoing will allow to identify the potential of application of these fuels in the energy matrix of Colombia and define policies to accelerate their implementation.

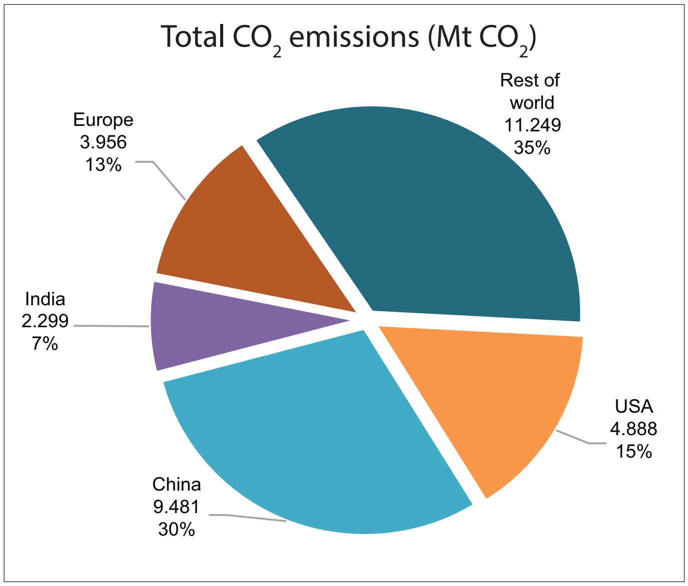
Keywords: Environmental Pollution, Energy Policy, Alternative Fuels, Hydrogen, Renewable Energy
JEL Classifications: L78, L90, O31, Q20

1. INTRODUCTION

The emissions of greenhouse gases have put life on our planet at risk as we know it today. An increase in the global temperature of two degrees at the end of the century will cause irreversible damage to the atmosphere, increasing the level of the oceans due to the accelerated thawing, and in greater quantity, of the poles (UN-FCCC, 2015). In China, the country with the highest CO_2 emissions as shown in Figure 1, studies claim that about 400,000 premature deaths occur annually due to air pollution, mainly due to respiratory and cardiac conditions (Tak et al., 2012). Thermoelectric power plants, industry and the transport sector cover about 90% of the polluting emissions, which are the residue from the combustion of petroleum-based fuels used as raw material for the production of electrical, thermal and mechanical energy (IPCC, 2014; Caineng et al., 2016; Kalghatgi, 2018). Additionally, fossil fuels are a limited resource, and their extraction from the soil deteriorates the ecosystem and the habitat of many species (Johnston et al., 2018). As an alternative, worldwide efforts focus on the search for clean and renewable fuels that guarantee the sustainability of society without altering its development.

At present, different alternative fuels have been used in the partial or total replacement of fossil fuels, both in internal combustion engines and in the generation of electric power, reducing greenhouse gas emissions. Although the results are positive, the use of these fuels, still contributes significantly in the aforementioned problems, either from its production or in its final use (Masjuki et al., 2016; Qian et al., 2016; Bae and Kim, 2017; Carbot et al., 2017; Khandal et al., 2018; György and Bereczky, 2018). According to the government policies of countries such as Germany, Japan, and the EU, by 2050, greenhouse gas emissions must be reduced by 65% to avoid an increase in global temperature (Gondal, 2016).

Figure 1: CO_2 emissions worldwide



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

Hydrogen, the oldest and most abundant element of the planet, is considered the fuel of the future, since, from the combustion of it with oxygen, water is obtained, that is to say, 0% of polluting emissions, on the other hand, it is worth noting that it is not a source of primary energy, since it is not found in its elemental form in nature. Primary energies, such as electricity, thermal, or biomass, are required to obtain them (da Silva et al., 2016; Sinigaglia et al., 2019). In order to meet energy needs, the production of hydrogen must be done on a large scale. Now, the electrolysis of water (the process in which hydrogen is obtained by the decomposition of water by applying an electric current through two electrodes submerged in an electrolyte (Polverino et al., 2019)) at present is the method that allows obtaining hydrogen on a large scale. Although it is an expensive process, due to the high consumption of electrical energy that it requires (Moliner et al., 2016). Therefore, it is necessary a combination of alternative energy sources such as solar, wind, and hydraulic, to obtain hydrogen in a safe, sustainable, and environmentally friendly way (Ajanovic and Haas, 2018).

This study presents a global overview of government policies and projects focused on the use of hydrogen as an energy vector, establishing its different applications as raw material and alternative fuel. A sustainable alternative is presented through primary sources of clean and renewable energy. The objective of this document is to show the energy potential based on hydrogen economy in Colombia; which has a high potential in clean energy sources, such as wind, solar, and biomass.

Colombia is some country rich in water resources, hence 63.3% of the energy generated is by hydroelectric power plants, 29.4% by fossil fuel based energy sources and only 0.2% by renewable energy sources (UPME, 2018). The Ministry of Mines and Energy (MME), through the Energy Mining Planning Unit (UPME), establishes the energy development plan, currently, with resources based on fossil fuels. With the global environmental situation, the efforts of countries should be directed towards an alternative that provides natural stability, bringing 0% CO_2 emissions. In Colombia, the energy generated in hydroelectric power plants can be stored by producing hydrogen, and avoid shortages in times of drought.

2. NATIONAL CONTEXT

2.1. Energy Policies in Colombia

Colombia, through the MME, formulates and adopts timely policies, plans, programs, projects, legislation and regulations for the mining and energy sector in accordance with the guidelines of the national government, in order to guarantee efficient, reliable and good quality energy, as well as allowing access to an informed decision regarding the product that users acquire (DPN, 2018). In turn, the MME through the UPME, governed by Law 143 of 1994 and by decree number 1258 of 2013, plans the mining-energy development, supports the formulation and implementation of public policies and generates knowledge and information for a sustainable future (MME.co., 2019). In addition, in 1994 the Congress of the republic through Laws 142 and 143 created the Energy and Gas Regulation Commission (CREG), a purely technical entity that regulates the provision of residential, public services of electric power, fuel gas and public services of liquid fuels (CREG, 2019).

Colombia was one of the pioneering countries in Latin America in the development of legislation for efficient energy consumption, in 2001 through the issuance of Law 697, "Through which the rational and efficient use of energy is foster, use of alternative energies is promoted, and other provisions are dictated," all this seen as a social objective, which, not only is of public interest but of national convenience (Gobierno Nacional, 2001). But this, due to its slow regulation and little practical impact, showed that much more than law is needed to guarantee the development of such an ambitious initiative. However, one of the most outstanding contributions was the promotion of the Program for Rational and Efficient Use of Energy and Non-Conventional Sources (PROURE), which was created by Decree 3683 of 2003 together with the Non-Conventional Energy Sources (CIURE) (DPN, 2018).

On the other hand, with Decree 1760 of 2003, due to the reduction of oil reserves, the National Hydrocarbons Agency was created in order to separate role of the regulatory entity and oil company in charge of Ecopetrol (private sector company), making this an entity with greater efficiency (ANH, 2019).

At present, the Indicative Action Plan (PAI) 2017 - 2022 is who one that develops the PROURE through Resolution 41286 of 2016, which adopted the MME. Likewise, the PAI highlights the increase in the global energy efficiency goal to 2022, which reaches 9.05%, contemplating relevant actions in the transport and industry sectors, as the main energy consumers of the country (UPME, 2019).

2.2. Hydrogen Policies in Colombia

Currently, Colombia does not have an established policy for the regulation of the production and implementation of hydrogen as a fuel or alternative energy source. Therefore, companies in the sector that operate with this gas are governed by the rules of gas management industrial and international standards.

In relation to norms and resolutions that involve gases in a general way in Colombia, they are:

- Resolution 2949, Ministry of Commerce, Industry and Tourism, "by which the technical regulation applicable to the information of the original stamp, labeling and physical appearance of cylinders without high-pressure seams for industrial and medicinal gases is issued, imported or manufactured domestically for commercialization or use in Colombia" (Gobierno Nacional, 2012)
- Resolution 53026, of the Ministry of Commerce, Industry, and Tourism. Superintendence of Industry and Commerce, "by which they adopt definitive measures on the commercialization and the use of a product to avoid causing harm or damage to the health and integrity of consumers" (Gobierno Nacional, 2015)
- NTC 2505, Facilities for the supply of fuel gas for residential and commercial uses (ICONTEC, 2006)
- NTC 2880, Transport. Dangerous goods class 2 (compressed gases, liquefied gases, gases dissolved under pressure, and cryogenic liquids). Ground transportation conditions (ICONTEC, 2005)
- NTC 1692, Transport. Transport of dangerous goods: definitions, classification, marking, and labeling (ICONTEC, 2005a)
- NTC 4786-2, Transport of dangerous goods. Tanker for land transport. Part 2. Flammable liquids and fuel (ICONTEC, 2000).

3. ALTERNATIVE FUELS

As a potential option, alternative fuels emerged, with which it is sought to greatly reduce the use of fossil fuels and reduce greenhouse gas emissions (Shin et al., 2019). In addition, some of these fuels can even be used in conventional vehicles, without the need to modernize infrastructure, automobile or engines (Van Vliet et al., 2009), do it by partial or total substitution (Andrews and Shabani, 2011). However, consumer preferences must be taken into account, analyzing the acceptance of these, based on various factors (Linzenich et al., 2019).

3.1. Bioethanol

Unlike ethanol, which is derived from petroleum, this fuel is produced from biomass of certain plant species such as the cultivation of wheat, barley, corn, sugarcane, etc. The method ASTM D6866-05 (ASTM, 2005) is applied in order to determine the carbon content, using the radiocarbon analysis, which determines the nature of the liquid obtained. Bioethanol is also known for it is typically mixed with conventional gasoline at various percentages (Mączyńska et al., 2018), among the most common are E10 and E85 (10% and 85% of Bioethanol respectively), where the first can be implemented without the need of modifications in the engine. Despite its positive impact and advantages, it has generated doubts due to the fact that its raw material competes with the food sector and contributes to deforestation and increases in the price of certain foods.

Colombia, for its part, took the initiative with respect to this product as fuel through the Ministry of Environment, encouraged by a resolution promulgated in the United States in President Bush's mandate, thus recording in Resolution 898 (Gobierno Nacional, 1995), as a result, the use of this element of at least 2% by weight in the mixture with gasoline in the country was required, and subsequently it was ratified by Law 693, where rules are dictated on the use of fuel alcohols, stimuli are created for their production, commercialization, and consumption and other provisions are dictated (Gobierno Nacional, 2001a). Currently, E8 is mixed in the center-east of Colombia and, in the west, E10; consequently, the production of bioethanol has increased, as evidenced in Figure 2, where last year's demand stands out, being the tenth bioethanol producing country of sugarcane in the world, with 130 million gallons per year. Valle del Cauca is the region produces the most it, followed by Risaralda, Caldas, and Cauca (FedeBiocombustibles, 2016). Even so, it only reaches 0.8 percent compared to other leading countries in the production of this liquid as it is US (FedeBiocombustibles, 2018).

3.2. Biomethanol

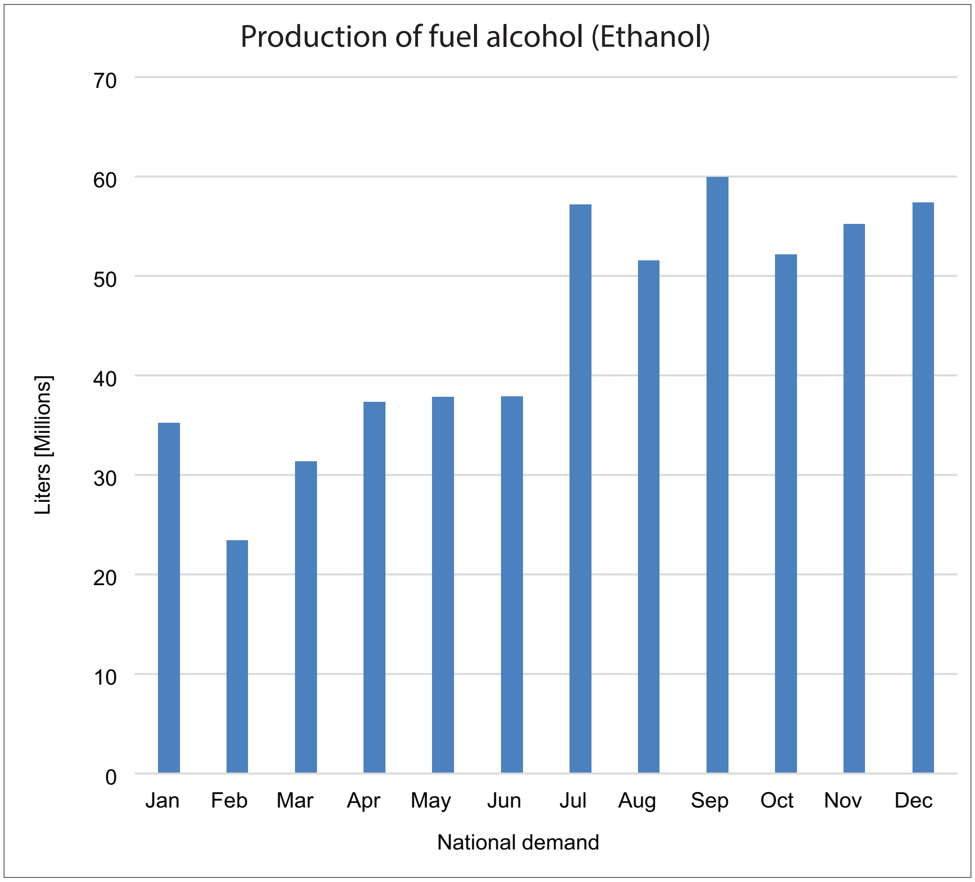
Also known as wood alcohol, it is alcohol, which has the simplest chemical structure and like Bioethanol, Biomethanol is produced from biomass (Minteer, 2011), but its production is more economical. It is usually mixed with fossil fuels such as gasoline and diesel, this latter mixture having a wide use in maritime transport. A disadvantage is its toxicity, low flash point, among others (Paulauskiene et al., 2019).

3.3. Natural Gas

Natural gas is a fossil fuel. Its composition varies according to location, climate, and other factors, and they have become an important part of global derivatives markets (Li, 2019). Furthermore, it is a source of energy for the industry and the home. It is also used as fuel for vehicles and as a chemical raw material in the manufacture of plastics and other commercial products (Chen et al., 2018). It is composed mainly of methane, and its combustion is one of the most environmentally friendly. On the other hand, the vehicles can only work with this fuel or in dual condition, for which it needs certain modifications, including a deposit for gas. But it has the advantage of being able to work with any of the two options, according to its availability.

As in the rest of the world, in Colombia, the participation in the demand for natural gas continues to be dominated by thermoelectric power plants and the industrial sector, which account for 57% of consumption and reach up to 75% if oil and petrochemical sector are included (UPME, 2016). Currently is the second most important primary energy resource for the electricity sector (Saldarriaga and Salazar, 2016); this participation highlights the importance of the availability of energy and competitive prices for the development of the different economic activities of the country.

Figure 2: Demand for Bioethanol in Colombia during 2018



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

3.4. Electricity

Since the twentieth century development of vehicles whose alternative energy source is electricity has been promoted, therefore, it is perhaps one of the most advanced topics worldwide, taking into account that electric vehicles must be designed only for such an end. These are classified into three main categories, which are: Battery electric vehicles (BEVs), fuel cell electric vehicles (FCHEVs) and hybrid electric vehicles (HEVs) (Wilberforce et al., 2017). Manufacturers such as Nissan, Renault, Tesla, Toyota, among others, have already available on the market electric cars since a long time with all the amenities and benefits. Despite their trajectory, they still tend to be expensive in their manufacturing process, and although they do not contaminate as fuel, depending on where the source is obtained, it still causes an impact on the environment (Sequeira and Santos, 2018).

3.5. Hydrogen

Hydrogen as an alternative fuel can be stored in a variety of ways and be produced from various resources, although many of these require large amounts of energy, usually associated with renewable energy which can be supplied in a country like Colombia being privileged because of its geographical position.

One of the main sectors to make use of hydrogen is transport (Moriarty and Honnery, 2019). Bearing in mind that it is the most abundant element in the earth, and when combusting, it does not generate polluting emissions. This has emerged as a great alternative to be used in the partial replacement of fossil fuel in internal combustion engines, greatly reducing the emissions of polluting gases. In addition, the use of hydrogen in fuel cells is the alternative with greater incidence and development in the automotive park (Winter, 2005; Murugan et al., 2019).

3.6. Biodiesel

Biodiesel is more prominent than other alternative fuels (Erdiwansyah et al., 2019), and its production is based on animal fats or vegetable oils (typically soy, rapeseed or sunflower) with a transesterification process that changes the properties of the oil significantly (Carraretto et al., 2004). In addition, biodiesel can also be mixed with pure diesel, which can be used in engines that were not modified, reducing pollutants gases.

In Colombia, its current production is 525,000 tons/year, equivalent to 170 million gallons from Cesar, Cundinamarca, Magdalena, Atlántico, Meta, and Santander, and it is marketed as a blend of B7 in the center-east of the country and, in the rest as B10; meaning, 7% and 10% of Biodiesel with 93% and 90% of Diesel respectively (FedeBiocombustibles, 2016).

4. RENEWABLE ENERGIES IN COLOMBIA

The main objective of the use of alternative fuels is to reduce polluting emissions, not only due to the residues of their combustion but also in their production process. In addition, the shortage of traditional sources of energy increased the concern on the part of governments to a greater extent (Harjanne and Korhonen, 2018). Thus, renewable energies became an ally and a possible solution to generate a greater positive impact on this aspect. Nevertheless, the social acceptance of renewable energies must be taken into account since it plays a fundamental role, especially in a developing country (Rosso and Kafarov, 2015).

Now, alternative or renewable energies are those alternatives for clean and friendly energy with the environment. Therefore, they do not pollute. These energies come from unlimited renewable natural resources such as solar radiation, wind, bodies of water, among others.

For its part, Colombia presents favorable conditions for the production of non-conventional renewable energies since it has great potential in the generation of this type of energies due to its geographical position and natural resources (UPME, 2015).

4.1. Wind Power

Wind energy is indirect energy that comes from solar since wind is air in movement generated by heat due to the incidence of the sun on the earth. It is completely free but noisy, and care must be taken not to affect the ecosystem, mainly the birds.

In representative capacities of wind power installed in 2014 in Latin America are Peru (148 MW), Panama (220 MW), Chile (836 MW), Mexico (2.3 GW) and Brazil (5.9 GW). Colombia produces 19.5 MW, an amount that, in comparison with the nations listed above is not competitive (Rueda et al., 2019). Although, taking into account that the wind resource in Colombia is not characterized as one of the best in general terms, it is available in certain localized regions of the country, as is the Caribbean region, as well as part of the departments of Santander and Norte de Santander, specific areas of Risaralda and Tolima, Valle del Cauca, Huila and Boyacá, which have usable resources; and to a greater extent the department of La Guajira, considered as one of the best in South America.

La Guajira concentrates the highest trade winds that the country receives throughout the year with average speeds close to 9 m/s (at 80 m height), and prevailing east-west direction (Huertas anf Pinilla., 2007), which are estimated to represent a potential energy that can be translated into an installable capacity of the order of 18 GW electric, in other words, almost 1.2 times the generating capacity installed in the SIN in December 2014 (15,465 MW) (UPME, 2015). Table 1 presents the potentials in MW of the main wind energy regions in the country.

However, Colombia still faces significant barriers to be addressed, associated with factors such as connection and access infrastructure, its integration and acceptance by the local community, its participation in the wholesale energy market and the valuation of wind energy as a source of generation complementary to the water matrix, among others (UPME, 2015).

Table 1: Wind potential in the regions of Colombia

Area	Wind potential (MW of installable capacity
Costa Norte	20,000
Santanderes	5000
Boyacá	1000
Risaralda - Tolima	1000
Huila	2000
Valle del Cauca	500

Source of data: Prepared by the authors based on data from (UPME, 2015)

4.2. Solar Energy

Solar energy today represents the second most advanced source of renewable energy with the highest penetration in the world, after wind energy. According to the solar radiation atlas of the UPME, particular regions of the country such as La Guajira, a good part of the Atlantic Coast and other specific regions in the departments of Arauca, Casanare, Vichada and Meta, among others, present levels of radiation above the national average that can reach the order of 6.0 kWh/m^2/d (UPME, 2015).

In the national energy sector, solar energy as well as wind energy, are postulated as great candidates to provide considerable benefits to the country, but again the lack of policies, technologies, financing programs, and awareness have taken us away from the privilege of its exploitation.

4.3. Biomass Energy

It is one of the main alternatives, because it contributes to the elimination of waste, thus obtaining fuel, electric power, among others. In addition, it is one of the most economical since it can be obtained from animal or vegetable waste.

In Colombia, for this purpose, waste from the sugarcane sector is used to a large extent, which in 2017 contributed to the generation of electricity in 793 MWh (UPME, 2015). Although current policies do not promote the development of this type of technology in the country, the use of biomass as a source of renewable energy represents a focus of interest in which it is worthwhile for Colombia to make policy efforts to make viable opportunities for rural development in which the self-supply of energy from these sources is the driving force for the development of agro-industry (UPME, 2015).

5. WORLDWIDE OVERVIEW AND APPLICATIONS

5.1. United States

Hydrogen has been used as an alternative energy source in the United States since the 1960s. NASA employed a hydrogen-oxygen fuel cell to supply auxiliary power for intermediate-duration space missions (Post, 1969). Currently, the state of California is a pioneer in the development, manufacture, and implementation of fuel cells in vehicles that guarantee the same operational conditions as those driven by conventional fuels. California Fuel Cell Partnership (CaFCP), 20 years ago with the collaboration of automobile manufacturers, energy companies, governmental and non-governmental agencies, and universities; initiated this great project based on the economy of hydrogen, as a result, in July 2018 about 5,000 vehicles pass through the streets of the state with 0% polluting emissions, also with 35 hydrogen supply stations and 29 under construction. By 2030, a total of 1,000 hydrogen stations and 1,000,000 decarbonized vehicles are expected (CaFCP, 2018).

5.2. Northern Netherlands

Being a country with a strong economy based on the exploitation of natural gas, by 2050 plans to change its economic model to a 100% green, based on the use of hydrogen. In addition, hydrogen and natural gas have similar characteristics; therefore, having the infrastructure, experience, and knowledge in the extraction of the latter, the Northern Netherlands pretend to be a leader in this economy and meet the objectives set in the Paris commission. In addition, the extraction of natural gas produces tremors that affect the integrity of its inhabitants, additional reason to make the imminent change. To produce hydrogen from clean energies, an investment of 5.5 to 10 billion euros will be made up to 2030, much of it in alternative energy sources such as offshore wind, hydroelectric and biomass; sources of primary energies for obtaining hydrogen on a large scale (EBNN, 2017; Honselaar et al., 2018).

Shell, the most important company in this country, conducted a study on the feasibility of the hydrogen economy and its different applications. As a raw material, hydrogen is mainly used in the manufacture of synthetic ammonia (fertilizer) and synthetic methanol. In addition, in techniques called hydrocracking and hydrotreatment in the refinery of oils and hydrogenation in vegetable oils. Because of its energy potential, hydrogen is used as a secondary energy source and storage of chemical energy; it is also used in internal combustion engines. Its application with greater relevance is in fuel cells, being the PEMFC type (low-temperature polymer electrolyte membrane fuel cell) that dominates the world market and secondly, the type solid oxide fuel cell. The Shell company conducted this study on hydrogen as the energy source of the future focused, especially on FCEVs (Shell, 2017).

5.3. European Union

Hydrogen is necessary for the energy transformation of the European Union countries. According to the Intergovernmental Panel on Climate Change (IPCC), the global temperature should not exceed 1.5 degrees Celsius, and CO_2 emissions should decrease by 45% by 2030. Then, generating 2250 TWh of hydrogen by 2050 represents approximately one-quarter of the total energy demand in the EU. In addition, under these conditions, an average of 42 million cars, 1.7 million trucks, approximately a quarter of a million buses, and more than 5,500 trains would be supplied with fuel. In achieving this objective, the European Union would achieve a reduction of 560 Mt of CO_2 emissions by 2050. In the residential sphere, hydrogen could replace an estimated 7% by volume of natural gas in 2030, and 32% for 2040, equivalent to 120 TWh. To achieve this objective, joint action is needed between regulations and research towards the development of fuel cells and electrolyzers to guarantee a source of clean and sustainable energy (FCH JU, 2019).

5.4. Argentina

Diesel fuel has a high demand in Argentina, mainly in the transport sector. In search of an alternative that allows this country to join the global efforts to mitigate greenhouse gas emissions, on 2006 the Congress approved Law 26093 that regulates the integral use of biofuels, which was implemented by the government executive in Decree 109 of 2007. With a Biodiesel and Bioethanol initiative of 5% (B5 and E5), projected at 15 years. In addition, Argentina has a strong agroindustrial development in the production of soy. Therefore, the transition from the soy industry as food to soy as an alternative fuel aims to become low-cost and sustainable alternative energy by the high production of this resource in this country (Mathews and Goldsztein, 2008).

As for the hydrogen economy, in Argentina, there are currently no laws that promote the development of this economy. However, different studies show its energy potential in the production of hydrogen via water electrolysis, with alternative energy sources such as solar, wind, and biomass. The province of Córdoba, the second with the most contamination by the transport sector, could supply the energy demand of fossil fuel for hydrogen fuel produced from wind energy with attractive costs (Rodríguez et al., 2010; Sigal et al., 2015). In addition, the natural gas industry plays an important role in the economy of the country, so the mixture of 20% v/v of this fuel and hydrogen, is a tangible initiative that allows a good start in the emerging economy based on hydrogen (Sigal et al., 2014).

5.5. Brazil

Brazil has a strongly consolidated economy in the exploitation of hydrogen as raw material, in the production of ammonia to manufacture fertilizer and a high potential for its use as an alternative fuel through the use of fuel cells in automobiles. Hydrogen in Brazil is obtained through the reforming of natural gas, a process that contributes to the increase in greenhouse gas emissions. This is where the use of alternative energies for the production of clean hydrogen comes into play, supported by government policies (da Silva et al., 2018).

Of Brazil's energy matrix, 44.8% was produced by alternative energy sources (RES) to 2010, and an increase to 46.3% is expected for 2020, as well as a 39% reduction in CO_2 emissions. In Brazil, it is possible to obtain hydrogen from renewable sources and fossil fuels by different processes: water electrolysis, reforming of natural gas and ethanol, and gasification of biomass (da Silva et al., 2018; da Silva et al., 2017).

The MME of Brazil is responsible for implementing energy policies in this country. In 2005, it launched the roadmap to structure the hydrogen economy in Brazil, which presents the economic base for the production of hydrogen from ethanol, water, and biomass from 2020 to 2030. In addition, through Decree 61.981 of 1967, the ministry is responsible for the management of energy resources, such as hydrogen (da Silva et al., 2018)

As potential use of renewable energies for the production of hydrogen, in the state of Ceará, an energy potential of wind power of 35 GW is estimated, which corresponds to approximately 40% of the capacity of electric power production in Brazil. For 2011 in the same state, private and commercial solar plants, in the city of Tauá, reached 1 MW of electric power. In the biological context, research is developed for the production of hydrogen at low cost and high production rate from residual organic matter using fermentative microorganisms (Silva et al., 2017; Esteves et al., 2015).

6. POTENTIAL APPLICATIONS OF HYDROGEN IN COLOMBIA

As Colombia is a developing country, it has a great potential to use hydrogen as a fuel, since several of the main economic sectors generate too much pollution to the environment, due to the extensive use of Diesel engines, which, despite that they are one of the main sources to supply the rapid growth of energy consumption and are used due to their greater durability and efficiency; they have a high incidence in pollution and considerably affect the health of the inhabitants; Above all, this negative contribution is made by the industrial and transport sector.

Today in Colombia, there are 8 cities that have an integrated mass transport system, to which much of the pollution present in these metropolitan areas is attributed. With hydrogen as an energy source to produce electricity, the impact on the environment caused by use fossil fuels would be considerably reduced, besides giving the possibility of obtaining greater efficiency in the use of this energy, diversifying the use of energy sources and having lower dependence on oil derivatives (Mejía and Acevedo, 2013). Simultaneously you can work with vehicles that use Biodiesel as fuel and perform a partial replacement; since currently, there are companies which work with the partial substitution of hydrogen in conventional vehicles, without modifications in the engine, only making use of its electronic injection system, opening a window of opportunity to be able to implement this partial replacement system in a broader spectrum of vehicles in Colombia.

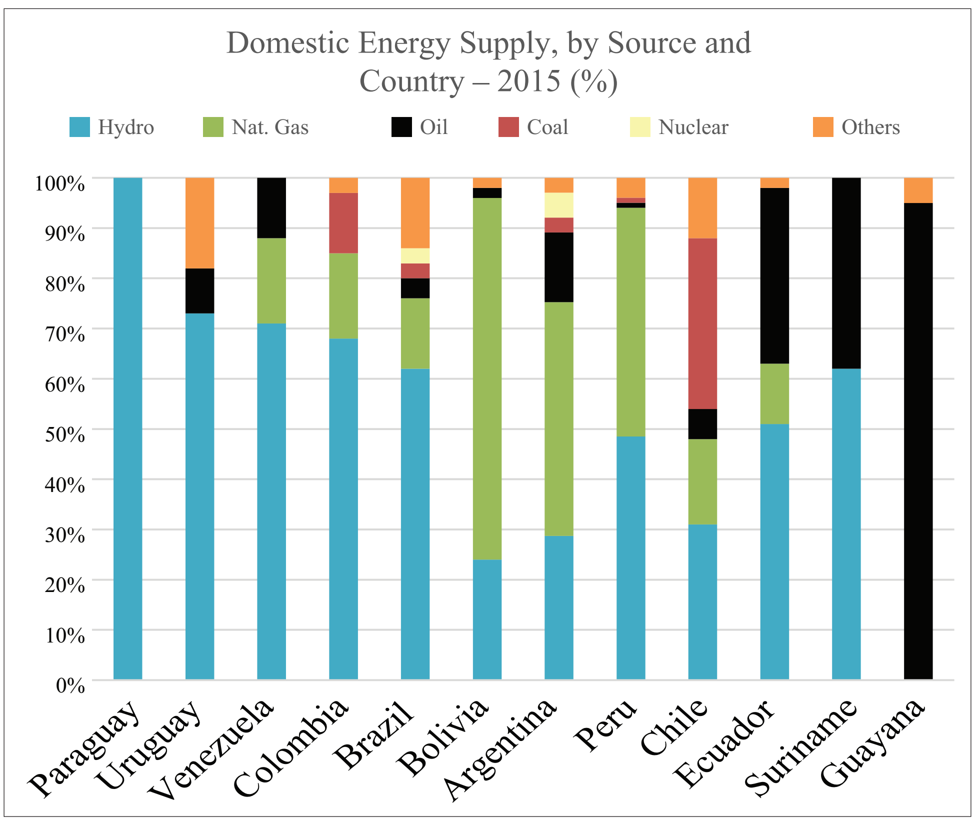
In addition, the country, due to the attractiveness of its geographical position, is projected as the main candidate to be a production and distribution center in South America, playing a vital role in the construction of a future hydrogen economy in this area (Martínez et al., 2013), in which, most of the electricity generated is in charge of the hydroelectric plants, as shown in Figure 3.

7. CONCLUSIONS

Due to the awareness of climate change by governments, especially the great powers such as the Netherlands, Germany, the United States, and others; the oil crisis and the negative impact on the health of human beings; the road to follow clearly was directed towards alternative fuels by the hand of renewable energies. For its part, hydrogen has gained space as an alternative to clean and friendly fuel with the environment, which also has many benefits.

Colombia has enough renewable resources to take advantage of hydrogen's greatest potential in the near future. Therefore, it positions it as an economic and environmental viability option, contributing to the sustainable development of the hydrogen economy, where not only is it seen as a source of energy or fuel, but everything that is required for its production, storage, transportation, etc. It also presents very useful applications, which directly contribute to the energy development of Latin America and, in general, globally through solar, wind, and biomass energy, where their potential applications are directed towards the industry and the transport sector, which, by using Diesel engines, participate to a large extent as part of the problem.

Figure 3: Domestic energy supply in the south of America



Source of data: Prepared by the authors based on data from (MME.br., 2016)

In the countries of South America, a high percentage of electricity is generated in hydroelectric power plants, as shown in Figure 3. This makes it a scenario with a high potential to successfully enter into the emerging hydrogen economy. On the other hand, the disadvantage of the high dependence on hydroelectric power lies in the times of drought, where the level of the reservoirs decreases, affecting their production capacity. It is then, where the hydrogen becomes a solution with multiple benefits. The energy generated in the hydroelectric plants, through the electrolysis of water, is transformed into chemical energy by producing hydrogen of high purity. This energy can now be transported and stored in a more efficient way. In addition, it can be used to drive vehicles with 0% polluting emissions, as a partial substitute in internal combustion engines and mixed with natural gas (Gondal, 2016), the second fuel used in South America to generate electric power and is an advantage because they have connections between countries, which could also be used for the transport of hydrogen, generating a sustainable economy.

Then, Colombia must follow a path that directs it towards the economy of the future, of hydrogen as an energy vector. In which, the intervention is key, from a legal and social framework, by the government that promotes scientific, technical and industrial development in the design, implementation, and use of renewable energies, mitigating greenhouse gas emissions and projecting towards this emerging economy.

REFERENCES

Ajanovic, A., Haas, R. (2018), Economic prospects and policy framework for hydrogen as fuel in the transport sector. Energy Policy, 123, 280-288.

Andrews, J., Shabani, B. (2011), Re-envisioning the role of hydrogen in a sustainable energy economy. International Journal of Hydrogen Energy, 37, 1184-1203.

ANH. (2019), Agencia Nacional de Hidrocarburos (ANH)-Historia. Available from: http://www.anh.gov.co/la-anh/Paginas/historia.aspx. [Last accessed on 2019 Jun 10].

ASTM. (2005), D6866-05 Standard Test Methods for Determining the Biobased Content of Natural Range Materials Using Radiocarbon and Isotope Ratio Mass Spectrometry Analysis. Available from: https://www.astm.org/DATABASE.CART/HISTORICAL/D6866-05.htm. [Last accessed on 2019 Jun 11].

Bae, C., Kim, J. (2017), Alternative fuels for internal combustion engines. Proceedings of the Combustion Institute, 36, 3389-3413.

CaFCP. (2018), California Fuel Cell Partnership. The California Fuel Cell Revolution: A Vision for Advancing Economic, Social, and Environmental Priorities. Available from: https://www.cafcp.org/sites/default/files/CAFCR.pdf. [Last accessed on 2019 Jun 11].

Caineng, Z., Qun, Z., Guosheng, Z., Xiong, B. (2016), Energy revolution: From a fossil energy era to a new energy era. Natural Gas Industry B, 3, 1-11.

Carbot, D.A., Escobar, R.F., Gómez, J.F., Téllez, A.C. (2017), A survey on modeling, biofuels, control, and supervision systems applied in internal combustion engines. Renewable and Sustainable Energy Reviews, 73, 1070-1085.

Carraretto, C., Macor, A., Mirandola, A., Stoppato, A., Tonon, S. (2004), Biodiesel as alternative fuel: Experimental analysis and energetic evaluations. Energy, 29, 2195-2211.

Chen, H., He, J., Zhong, X. (2018), Engine combustion and emission fuelled with natural gas: A review. Journal of the Energy Institute, 92, 1123-1136.

CREG. (2019), Comisión de Regulación de Energía y Gas-Misión y Visión. Available from: http://www.creg.gov.co/creg/quienes-somos/mision-y-vision. [Last accessed on 2019 Jun 08].

da Silva, A., da Silva, T., Veras, S., Simonato, T., da Costa, D., Conejero, M.A. (2018), Hydrogen productive chain in Brazil: An analysis of the competitiveness' drivers. Journal of Cleaner Production, 207, 751-763.

da Silva, T., Mozer, T.S., da Costa, D., da Silva, A. (2016), Hydrogen: Trends, production, and characterization of the main process worldwide. International Journal of Hydrogen Energy, 42, 2018-2033.

DPN. (2018), Departamento Nacional de Planeación. Energy Demand Situation in Colombia. Available from: https://www.dnp.gov.co/Crecimiento-Verde/Ejes-estrategicos/Paginas/Eficiencia-energ%C3%A9tica.aspx. [Last accessed on 2019 Jun 27].

EBNN. (2017), Economic Board Noord-Nederland. The Green Hydrogen Economy in the Northern Netherlands. Available from: https://www.ebnn-nieuw.nl/wp-content/uploads/2019/05/NIB-Hydrogen-Full_report.pdf. [Last accessed on 2019 Jun 29].

Energy in South America. (2016), Year of Reference: 2015. Available from: http://www.mme.gov.br/documents/10584/3580500/05+-+Energy+in+South+America+%28Year+-+2015%29+%28PDF%29/503b06ae-aafb-47e9-84cd-c0acf7028005?version=1.2. [Last accessed on 2019 Jul 04].

Erdiwansyah, Mamat, R., Sani, M.S.M., Sudhakar, K., Kadarohman, A. (2019), An overview of Higher alcohol and biodiesel as alternative fuels in engines. Energy Reports, 5, 467-479.

Esteves, N.B., Sigal, A., Leiva, E.P.M., Rodríguez, C.R., Cavalcante, F.S.A., de Lima, L.C. (2015), Wind and solar hydrogen for the potential production of ammonia in the state of Ceará-Brazil. International Journal of Hydrogen Energy, 40, 9917-9923.

FCH JU. (2019), The Fuel Cells and Hydrogen Joint Undertaking. Hydrogen Roadmap Europe: A Sustainable Pathway for the European Energy Transition. Available from: https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf. [Last accessed on 2019 Jun 25].

FedeBiocombustibles. (2016), Boletín informativo No. 147 Miércoles 27 de Abril de 2016. Available from: http://www.fedebiocombustibles.com/nota-web-id-2543.htm. [Last accessed on 2019 Jun 28].

FedeBiocombustibles. (2018), Boletín informativo No. 189 Miércoles 12 de Septiembre de 2018. Available from: http://www.fedebiocombustibles.com/nota-web-id-3064.htm. [Last accessed on 2019 Jun 28].

FedeBiocombustibles. (2019), Demanda Nacional de Alcohol Carburante (Etanol). Available from: https://www.fedebiocombustibles.com/estadistica-produccion-titulo-Alcohol_Carburante_(Etanol).htm. [Last accessed on 2019 Jun 28].

Gobierno Nacional. (1995), Resolucion 898. Por la Cual se Regulan los Criterios Ambientales de Calidad de los Combustibles Líquidos y Sólidos Utilizados en Hornos y Caldera de Uso Comercial e Industrial y en Motores de Combustión Interna de Vehículos Automotores. Available from: http://www.minambiente.gov.co/images/AsuntosambientalesySectorialyUrbana/pdf/emisiones_atmosfericas_contaminantes/fuentes_moviles/Resolucion_898_de_1995_-_Calidad_Combustibles.pdf. [Last accessed on 2019 Jun 26].

Gobierno Nacional. (2001), Ley 697. Mediante la Cual se Fomenta el Uso Racional y Eficiente de la Energía, se Promueve la Utilización de Energías Alternativas y se Dictan Otras Disposiciones. Bogotá, Colombia: Congreso de la República de Colombia. Available from: http://www.upme.gov.co,81/sgic/?q=content/ley-697-de-2001. [Last accessed on 2019 Jun 26].

Gobierno Nacional. (2001a), Ley 693. Por la Cual se Dictan Normas Sobre el Uso de Alcoholes Carburantes, se Crean Estímulos para su Producción, Comercialización y Consumo, y se Dictan Otras Disposiciones. Available from: http://www.secretariasenado.gov.co/senado/basedoc/ley_0693_2001.html. [Last accessed on 2019 Jun 26].

Gobierno Nacional. (2012), RESOLUCION 2949. Por la Cual se Expide el Reglamento Técnico Aplicable a la Información del Estampe Original, Etiquetado y Aspecto Físico de Cilindros Sin Costuras de Alta Presión para Gases Industriales y Medicinales, que se Importen o se Fabriquen Nacionalmente para su Comercialización o Uso en Colombia. Available from: http://www.suin-juriscol.gov.co/viewDocument.asp?id=4026664. [Last accessed on 2019 Jun 26].

Gobierno Nacional. (2015), Resolucion 53026 DE 2015. Por la Cual se Adoptan Medidas Definitivas Sobre la Comercialización y el Uso de un Producto para Evitar que se Cause Daño o Perjuicio a la Salud e Integridad de los Consumidores. Available from: http://www.suin-juriscol.gov.co/viewDocument.asp?ruta=Resolucion/30035571. [Last accessed on 2019 Jun 26].

Gondal, I.A. (2016), Hydrogen transportation by pipelines. Compendium of Hydrogen Energy, 2, 301-322.

György, S., Bereczky, A. (2018), Experimental investigation of physicochemical properties of diesel, biodiesel and TBK-biodiesel fuels and combustion and emission analysis in CI internal combustion engine. Renewable Energy, 121, 568-578.

Harjanne, A., Korhonen, J.M. (2019), Abandoning the concept of renewable energy. Energy Policy, 127, 330-340.

Honselaar, M., Pasaoglu, G., Martens, A. (2018), Hydrogen refueling stations in the Netherlands: An intercomparison of quantitative risk assessments used for permitting. International Journal of Hydrogen Energy, 43, 12278-12284.

Huertas, L., Pinilla A. (2007), Predicción de Rendimiento de Parques Eólicos Como Herramienta de Evaluación. Bogotá: Empresas Públicas de Medellín, Universidad de los Andes.

ICONTEC. (2000), Norma Técnica Colombiana, NTC 4786-2, Especifica Los Requisitos Minimos Para el Diseño, Construccion, Reparacion, Modificacion, Marcado, Rotulado y Operacion a los Cuales Deben Someterse Los Carrotanques Que se Destinan al Transporte de Liquidos Inflamables. Available from: https://www.icontec.org/Documentos%20compartidos/normas%20por%20sectores/43.pdf#search=4786%2D2. [Last accessed on 2019 Jun 26].

ICONTEC. (2005), Norma Técnica Colombiana, NTC 2880, Establece Los Requisitos Que Debe Cumplir el Transporte y Manejo Terrestre de Cilindros Que Contengan Mercancias Peligrosas de la Calse 2, Tales Como Gases Comprimidos, Gases Licuados (Excepto glp), Gases Disueltos Bajo Presion y Liquidos Criogenicos. Available from: https://www.icontec.org/Documentos%20compartidos/normas%20por%20sectores/13.pdf#search=2880. [Last accessed on 2019 Jun 26].

ICONTEC. (2005a), Norma Técnica Colombiana, NTC 1692, Establece la Clasificación de las Mercancías Peligrosas, las Definiciones, el Marcado, Etiquetado y Rotulado de Éstas Para Fines de Identificación del Producto y de Las Unidades de Transporte, Cuando se Desarrollen Actividades de Transporte en Sus Diferentes Modos. Available from: https://www.icontec.org/Documentos%20compartidos/normas%20por%20sectores/13.pdf#search=1692%202005. [Last accessed on 2019 Jun 26].

ICONTEC. (2006), Norma Técnica Colombiana NTC 2502, Instalaciones Para Suministro de Gas Combustible Destinadas a Usos Residenciales y Comerciales. Available from: https://www.icontec.org/Documentos%20compartidos/normas%20por%20sectores/91.pdf#search=2505. [Last accessed on 2019 Jun 26].

IEA. (2018), Global Energy and CO_2 Status Report. Available from: https://www.iea.org/geco/data. [Last accessed on 2019 Jun 26].

IPCC. (2014), Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available from: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_frontmatter.pdf. [Last accessed on 2019 Jun 21].

Johnston, J.E., Lim, E., Roh, H. (2018), Impact of upstream oil extraction and environmental public health: A review of the evidence. Science of the Total Environment, 657, 187-199.

Kalghatgi, G. (2018), Is it really the end of internal combustion engines and petroleum in transport? Applied Energy, 225, 965-974.

Khandal, S.V., Banapurmath, N.R., Gaitonde, V.N. (2018), Effect of hydrogen fuel flow rate, fuel injection timing and exhaust gas recirculation on the performance of dual fuel engine powered with renewable fuels. Renewable Energy, 126, 79-94.

Li, B. (2019), Pricing dynamics of natural gas futures. Energy Economics, 78, 91-108.

Linzenich, A., Arning, K., Bongartz, D., Mitsos, A., Ziefle, M. (2019), What fuels the adoption of alternative fuels? Examining preferences of German car drivers for fuel innovations. Applied Energy, 249, 222-236.

Mączyńska, J., Krzywonos, M., Kupczyk, A., Tucki, K., Sikora, M., Pińkowska, H., Bączyk, A., Wielewska, I. (2018), Production and use of biofuels for transport in Poland and Brazil the case of bioethanol. Fuel, 241, 989-996.

Martínez, A., Barreneche, D., Bellon, D., Plata, D., Latorre, D., Porras, A., Rincón, A. (2013), Estudio de Factibilidad de la Economia del Hidrógeno en Colombia. Cartagena: WEEF.

Masjuki, H.H., Ruhul, A.M., Mustafi, N.N., Kalam, M.A., Arbab, M.I., Rizwanul, I.M. (2016), Study of production optimization and effect of hydroxy gas on a CI engine performance and emission fueled with biodiesel blends. International Journal of Hydrogen Energy, 41, 14519-14528.

Mathews, J.A., Goldsztein, H. (2009), Capturing latecomer advantages in the adoption of biofuels: The case of Argentina. Energy Policy, 37, 326-337.

Mejía, J.G., Acevedo, C.A. (2013), Proyección al año 2025 para el uso del hidrógeno en el sector transporte del valle de Aburrá. Scientiae et Technica Año XVIII Universidad Tecnológica de Pereira, 18, 327-334.

Minteer, S.D. (2011), Biochemical production of other bioalcohols: Biomethanol, biopropanol, bioglycerol, and bioethylene glycol. Handbook of Biofuels Production. Cambridge: Woodhead. p258-265.

MME.co. (2019), Ministerio de Minas y Energía-Misión y Visión. Available from: https://www.minenergia.gov.co/mision-y-vision. [Last accessed on 2019 Jul 02].

Moliner, R., Lazáro, M.J., Suelves, I. (2016), Analysis of the strategies for bridging the gap towards the hydrogen economy. International Journal Hidrogen Energy, 41, 19500-19508.

Moriarty, P., Honnery, D. (2019), Prospects for hydrogen as a transport fuel. International Journal of Hydrogen Energy, 44, 16029-16037.

Murugan, A., De Huu, M., Bacquart, T., Van Wijk, J., Arrhenius, K., Te Ronde, I., Hemfrey, D. (2019), Measurement challenges for hydrogen vehicles. International Journal of Hydrogen Energy, 44, 19326-19333.

Paulauskiene, T., Bucas, M., Laukinaite, A. (2019), Alternative fuels for marine applications: Biomethanol-biodiesel-diesel blends. Fuel, 248, 161-167.

Polverino, P., D'Aniello, F., Arsie, I., Pianese, C. (2019), Study of the energetic needs for the on-board production of oxy-hydrogen as fuel additive in internal combustion engines. Energy Conversion and Management, 179, 114-131.

Post, R.E. (1969), Effect of Temperature and Electrolyte Concentration on Performance of a Fuel Cell of the Bacon Type. NASA Technical Report TN D-5154.

Qian, Y., Sun, S., Ju, D., Shan, X., Lu, X. (2017), Review the state-of-the-art of biogas combustion mechanims ans applications in internal combustion engines. Renewable and Sustainable Energy Reviews, 69, 50-58.

Rodríguez, C.R., Riso, M., Jímenez, G., Ottogalli, R., Cruz, R.S., Aisa, S., Jeandrevin, G., Leiva, E.P.M. (2010), Analysis of the potential for hydrogen production in the province of Córdoba, Argentina, from wind resources. International Journal of Hydrogen Energy, 35, 5952-5596.

Rosso, A.M., Kafarov, V. (2015), Barriers to social acceptance of renewable energy systems in Colombia. Current Opinion in Chemical Engineering, 10, 103-110.

Rueda, J.G., Guzmán, A., Guzmán, A., Cabello, J.J., Silva, R., Bastidas, E., Horrillo, J. (2019), Renewables energies in Colombia and the opportunity for the offshore wind. Journal of Cleaner Production, 220, 529-543.

Saldarriaga, C., Salazar, H. (2016), Security of the Colombian energy supply: The need for liquefied natural gas regasification terminals for power and natural gas sectors. Energy, 100, 349-362.

Sequeira, T.N., Santos, M.S. (2018), Renewable energy and politics: A systematic review and new evidence. Journal of Cleaner Production, 192, 553-568.

Shell. (2017), Shell Hydrogen Study Energy of the Future? Sustainable Mobility through Fuel Cells and H_2. Available from: https://www.shell.com/energy-and-innovation/new-energies/hydrogen/_jcr_content/par/textimage_1062121309.stream/1496312627865/6a3564d61b9aff43e087972db5212be68d1fb2e8/shell-h2-study-new.pdf. [Last accessed on 2019 Jul 03].

Shin, J., Hwang, W.S., Choi, H. (2019), Can hydrogen fuel vehicles be a sustainable alternative on vehicle market?: Comparison of electric and hydrogen fuel cell vehicles. Technological Forecasting and Social Change, 143, 239-248.

Sigal, A., Cioccale, M., Rodríguez, C.R., Leiva, E.P.M. (2015), Study of the natural resource and economic feasibility of the production and delivery of wind hydrogen in the province of Córdoba, Argentina. International Journal Hidrogen Energy, 40, 4413-4425.

Sigal, A., Leiva, E.P.M., Rodríguez, C.R. (2014), Assessment of the potential for hydrogen production from renewable resources in Argentina. International Journal of Hydrogen Energy, 39, 8204-8214.

Silva, F.M.S., Oliveira, L.B., Mahler, C.F., Bassin, J.P. (2017), Hydrogen production through anaerobic co-digestion of food waste and crude glycerol at mesophilic conditions. International Journal Hydrogen Energy, 42, 22720-22729.

Sinigaglia, T., Evaldo, T., Kreimeier, F., Martins, M.E.S. (2019), Use of patents as a tool to map the technological development involving the hydrogen economy. World Patent Information, 56, 1-8.

Tak, I., Zhang, Y., Wai, W., Hua, Q., Xu, Y., Xun, X., Wu, W., Ma, W., Wei, L., Ah, L., Qian, X. (2012), Effect of ambient air pollution on daily mortality rates in Guangzhou, China. Atmospheric Environment, 46, 528-535.

UN-FCCC. (2015), Adoption of the Paris Agreement. Available from: https://www.unfccc.int/resource/docs/2015/cop21/eng/l09.pdf. [Last accessed on 2019 Jul 05].

UPME. (2015), Integración de las Energías Renovables no Convencionales en Colombia. Available from: http://www1.upme.gov.co/DemandaEnergetica/INTEGRACION_ENERGIAS_RENOVANLES_WEB.pdf. [Last accessed on 2019 Jun 23].

UPME. (2016), Proyección de Gas Natural en Colombia 2016-2030. Available from: http://www1.upme.gov.co/DemandaEnergetica/Proyeccion_Demanda_Gas_Natural_Noviembre2016.pdf#search=gas%20natural. [Last accessed on 2019 Jun 23].

UPME. (2018), Energía Eléctrica SIN (Sistema Interconecntado Nacional). Available from: http://www1.upme.gov.co/InformacionCifras/Paginas/PETROLEO.aspx. [Last accessed on 2019 Jun 23].

UPME. (2019), PROURE-Programa de Uso Racional y Eficiente de Energía y Fuentes No Convencionales. Available from: http://www1.upme.gov.co/Paginas/PROURE.aspx. [Last accessed on 2019 Jun 23].

Van Vliet, O.P.R., Faaij, A.P.C., Turkenburg, W.C. (2009), Fischer tropsch diesel production in a well-to-wheel perspective: A carbon, energy flow, and cost analysis. Energy Conversion and Management, 50, 855-876.

Wilberforce, T., El-Hassan, Z., Khatib, F.N., Al Makky, A., Baroutaji, A., Carton, J.G., Olabi, A.G. (2017), Developments of electric cars and fuel cell hydrogen electric cars. International Journal of Hydrogen Energy, 42, 25695-25734.

Winter, C.J. (2005), Into the hydrogen energy economy milestones. International Journal of Hydrogen Energy, 30, 681-685.