Colombian Clean Fuel Matrix: Current Scenario and Opportunities for Biofuels Enhancement

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Abstract

In Colombia, since 2005, diverse technologies for biofuels production have been studied and implemented in the search for alternatives to fossil fuels. The main biofuels produced in the Colombian fuel matrix are bioethanol and biodiesel. Only few cases are reported on industrial biogas production. This study presents the Colombian biofuel potential and the actions expected for its development in the national market. The main findings of this research study are: Colombian biofuels regulatory framework is constantly being updated, strategies for the development of bio-based economies on rural areas in small-scale production facilities is being promoted, and sustainable rural developments practices based on GIS modelling are being considered. The main objective of this paper is to evaluate the impact of biofuels on the transportation sector, to assess the opportunities for the Colombian fuel matrix, and to assess the preparedness of the regulation to promote and sustain biofuels on the market. Further research is expected to forecast biomass valorisation scenarios in which studies based on second generation biomass conversion technologies are needed to validate economic feasibility of new projects of industrial facilities.

Keywords: Biofuels, energy matrix, diversification strategies, regulatory framework.

1. Introduction

Due to the accelerated global energy consumption during recent years, governments have triggered an interest of reducing the dependence on fossil fuel and also to reduce the environmental impacts associated with their use (Musa, S. et Al., 2018). This situation has directed efforts of companies, government and academia to study the potential sources for energy production from different sustainable sources, including biomass (Abas, N. et al., 2015). Biomass resources refers to organic matter that could be used on a renewable basis, in which energy production and efficiency conversion depends on technology and biomass composition. Biomass feedstock mainly consists of: energy crops, forestry residues, biomass processing residues, municipal waste and animal waste, among others (Muench, S., 2015. Nogues, F., 2010). Energy from biomass offers a sustainable advantage related to both renewable heat and grid stability (Borsukiewicz-Gozdur, A. et al., 2015).

According to the International Renewable Energy Agency (IRENA), energy from biomass resources could be as high as 60% of the world renewable energy mix by 2030. It is estimated that 40% of this matter will be originated from agricultural residues and wastes (IRENA, 2012). Compared with other renewable energy sources such as solar, wind and geothermal energy, bioenergy stands as a mature technology and a sustainable opportunity for the agricultural sector, focusing on key particular government goals. Energy from biomass could represent an opportunity for the agricultural sector with the development of a new market based on energy generation, energy independence and by-products (biofertilizer) commercialization. Second and third generation biofuels production based on energy crops cultivated on abandoned arable lands of post-conflicted areas could also enhance governmental interest (Dorta-Santos, M. et al., 2015).

Understanding the technical advantages of conversion technologies of biomass is fundamental to enhance public and private acceptance. For that matter, conversion technologies associated to energy production from biomass can be divided in 2 major groups: thermal conversion and chemical conversion (Davies, A. et al., 2014, Ghosh, d. et al., 2015). Thermal conversion technology consists of a series of processes in which heat is utilized as the main mechanism to transform biomass substrates into another chemical form. These technologies can thus be classified in three subgroups: combustion, gasification and pyrolysis. Combined Heat and Power (CHP) and Co-Firing (CF) are great examples of their industrial application in different regions of the world. Other, not-very-common, applications of thermal conversion processes are: Hydrothermal Upgrading (HTU) and Hydroprocessing (Dahiya, A., 2014). On the other hand, chemical conversion is the process to transform biomass by a series of chemical processes into other forms with high energy potential. A biological variation of chemical process is the denominated "biochemical conversion"; enzymes of bacteria and other specialized microorganisms are key elements to breakdown molecules converting biomass into fuel. Common conversion technologies are: anaerobic digestion (biogas), alcoholic fermentation (bioethanol), composting (heat) and transesterification (biodiesel) (Cecchi F., et al., 2015, Saini, J.K., et al., 2015, Lourinho G., et al., 2015). Successful applications of biofuels at commercial and industrial facilities have been widely reported on the literature in which efforts have been conducted worldwide on innovative market policies for biofuels adoption and creating new markets for sustainable biofuel production. Nowadays, biofuel technology is the most important renewable energy source used in the transportation sector followed by commercially available electric transportation vehicles (Wi, S. G., et al., 2015). Biological conversion of organic matter into biomethane (biogas without CO_2, H_2O, and other traces) has proven to be a suitable alternative to fuel vehicles, which include cars, buses and trains.

In Colombia, bioethanol and biodiesel production are successfully integrated into the energy matrix. Biomass is harnessed from energy crops on a second generation biofuel basis. Research on biofuel potential have been conducted on different types of biomass to assess technology performance and approximate outputs expected at different Colombian sites (MME, 2013).

In 2011, Universidad Industrial de Santander (UIS) with the support of the Administrative Department of Science, Technology and Innovation –COLCIENCIAS, the Mining and Energy Planning Unit –UPME, and the Institute of Hydrology, Meteorology and Environmental Studies -IDEAM, developed an atlas of the energy potential of residual biomass in Colombia. The aim of the atlas was to characterize the energy potential of biomass residues in Colombia and to assess integration of biofuels into the national energy market. For the study three main sectors were assessed: 1) agricultural, 2) livestock, and 3) solid organic waste. The research was conducted based on the characterization of residues of different crops species, animals and municipal solid waste of 12 cities. Biomass samples were collected and characterized; databases, mathematical models and computer and mapping tools were structured, allowing the development of 425 maps (MME, 2013).

The aim of this paper is to evaluate the impact of biofuels on the transportation sector, to assess the opportunities for the Colombian fuel matrix, and to assess the preparedness of the regulation to promote and sustain biofuels on the market. The rest of this paper is organized as follows: Colombian fuel matrix, and actions for biofuels development in Colombia.

2. Colombian biofuel matrix

2.1 Biorefineries location

In Colombia, production of bioethanol is mostly centralized. In January 2018, there are 7 operational bioethanol industrial facilities: 5 located in the Valle del Cauca department, representing 78.7% of the total national production, and 2 located in the departments of Meta and Risaralda representing 22.3% of bioethanol yield. Bioethanol production has increased employment generation in which 3.584 direct and 100.353 indirect employments were created (Fedebiocombustibles, 2018).

For biodiesel, there are currently 12 operational biorefineries widely distributed on the national territory. Biorefineries are located in the following departments: 3 in Magdalena (30% of Total

Biodiesel Production - TBP), 2 in Atlantico (2% TBP), 2 in Santander (17% TBP), 2 in Meta (21% TBP), 1 in Antioquia (2% TBP), 1 in Cundinamarca (22% TBP), and 1 in Cesar (7% TBP). Employment attributed to biodiesel production has reported 29.062 direct and 58.123 indirect jobs. (Fedebiocombustibles, 2018)

2.2 Historic production and sales of biofuels on the national market

According to the Renewable Fuels Association (RFA), approximately 103 million cubic meters of bioethanol were produced in 2017, in which U.S. bioethanol production accounted for 58.4% of the total production, followed by Brazil with 26.1% and China with 3.2%. Additionally, the Renewable Energy Policy Network for the 21st Century, REN21, reported that world biodiesel production was approximately 24 million cubic meters in the world, with U.S. leading with 5.5 million cubic meters, followed by Brazil with 3.8 million cubic meters. Colombia has reported a total production of 0.5 million cubic meters by 2016.

Production of biofuels in Colombia has evidenced a continuous trend during the past years. In 2017, bioethanol and biodiesel remained stable during the whole period, except for bioethanol that suffered a falloff in May 2017 due to adverse climate effects (Fig. 1).

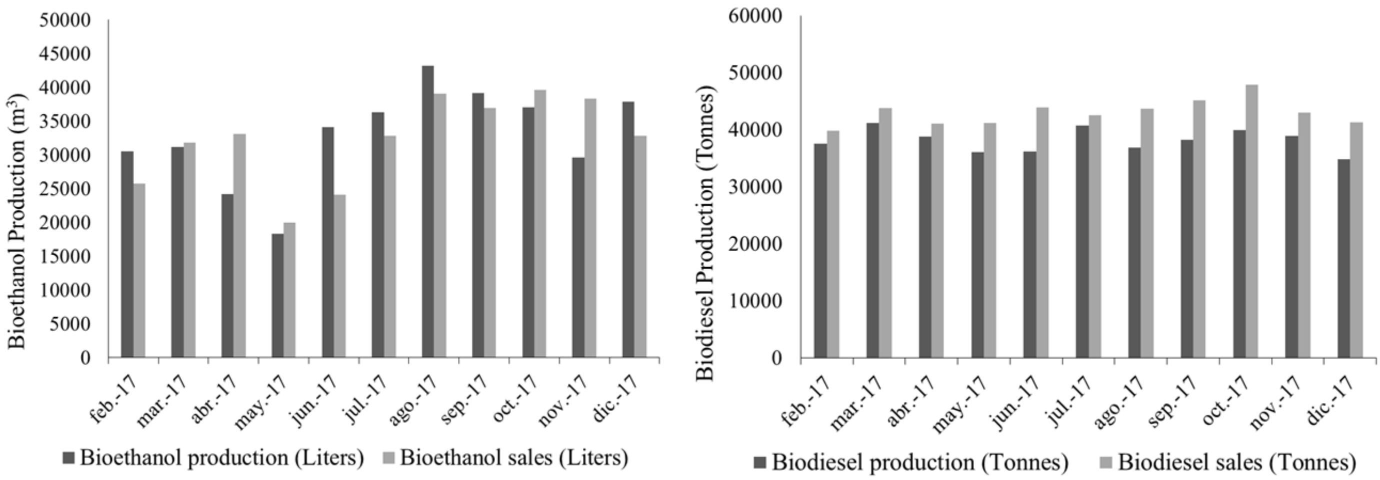

Fig. 1. Production and sales of bioethanol in Colombia: Adapted from https://www.fedebiocombustibles.com (Taken on February 10, 2018)

2.3 Biofuels pricing on the national market

Gasoline and diesel price regulation is issued periodically by the Colombian Ministry of Mines and Energy (Law No. 39, 1987). Fuel price structure is based on: a) maximum wholesale distributor price, b) maximum retailer price, c) producer income, and d) consumer price. Biofuels valuation is estimated based on international prices of refined sugar and palm oil. However, prices of biofuel blend also consider international prices of fossil fuels, producer income, transportation and marketing fees and retailer price margins. The Fig. 2 present historical pricing per gallon of biofuels compared with conventional fuels and blend mandates.

According to resolution 40183 of 2018, biodiesel is priced at $0.94 USD per litre, while bioethanol is priced at $0.70 USD per litre. However, imported biofuels from international markets are not affected by this mandate which promotes foreign investment in Colombia.

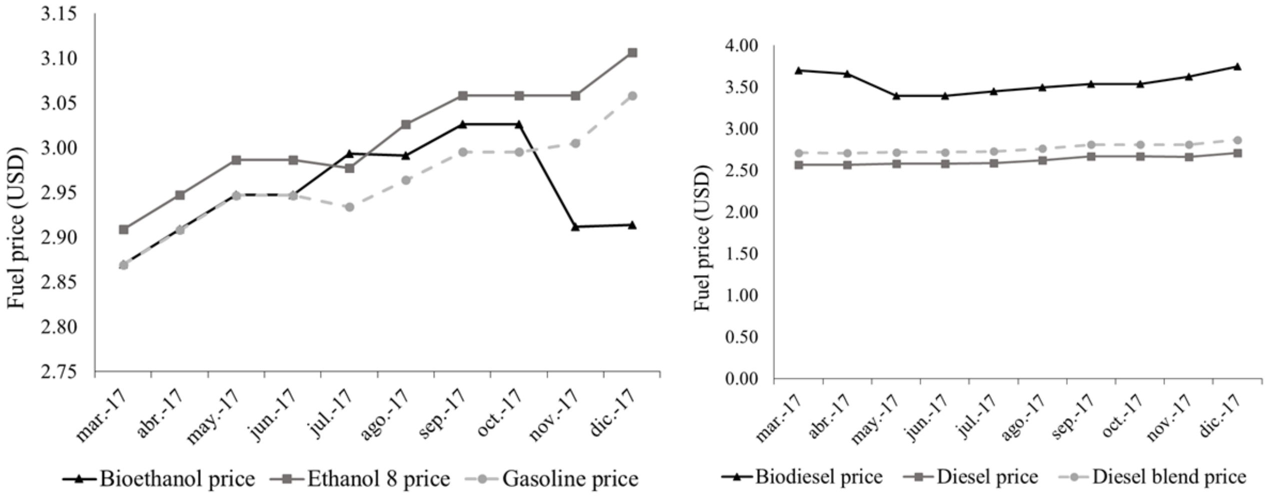

Fig. 2. Fossil fuels and biofuels prices´ trend in Colombia in 2017. Source: Adapted from https://www.fedebiocombustibles.com (Taken on February 10, 2018)

3. Actions for biofuels development in Colombia

The bioenergy technologies become at the same time a challenge and an opportunity in Colombia as its economy continues to develop. Different economic and research sectors have agreed that there is a great potential to structure a solid domestic bio-based economy based on substrate availability (Gonzalez-Salazar, M.A., et al., 2014a, Gonzalez-Salazar, M.A., et al., 2017). Additionally, innovation trends geared by innovative corporations located in the main cities of Colombia could lead to modernization of the energy and agricultural sector. As the state-of-the-art of bioenergy technology presents nowadays, there is still a lot of research to do and applications of existent technologies to be validated in different scenarios, specifically in Colombia due to its natural resources and strategic ecosystems (Gonzalez-Salazar, M.A., et al., 2014b).

Colombia is catalogued as one of the megadiverse countries, concept built by the Cancun initiative to promote the conservation and sustainable use of biologic diversity (O´Connor, C. et al., 2003). Land utilization for bioenergy purposes could represent a serious threat to the natural ecosystem and may negatively affect local economy for small farmers and indigenous people (Gardi, C. et al., 2015). To achieve proper penetration of bioenergy technologies based on sustainable practices, the national government should considered the following criteria: food-energy nexus, scale-up implications, price/incentives mechanisms, national bioenergy policies, proper communication mechanisms, new available crops for non-arable lands and more adapted land planning systems.

3.1 Colombian biofuel network

The Colombian federation of biofuels (Fedebiocombustibles) is the guild for biofuel producers. The role of the guild is to harvest and to communicate reported information, participate on sectorial policies decisions, encourage research and employment generation. It also aims at the protection of the environment and diversification of the energy matrix. Fedebiocombustibles consists of 7 companies for bioethanol production, 12 for biodiesel production, 2 growers associations, and governmental and academic institutions, as shown in Table 1.

3.2 Regulatory framework

Since 2001, the Colombian government has implemented a set of policy instruments oriented towards the promotion of biofuels through the National Development Plan (PND). This strategy is supported on a regulatory framework in which clear incentives for technology appropriation by different sectors are defined.

Table 1. Companies associated to Fedebiocombustibles

Company name	Type	Location
Fedepalma	Association	Bogota
Asocaña	Association	Bogota/Cali
BioSC S.A	Biodiesel Producer	Santa Marta
Odín Energy S.A	Biodiesel Producer	Bogota
BioCosta S.A.S	Biodiesel Producer	Santa Marta
Oleoflores S.A	Biodiesel Producer	Barranquilla
Ecodiesel de Colombia S.A	Biodiesel Producer	Bucaramanga
BioD S.A	Biodiesel Producer	Bogota
Aceites Manuelita S.A	Biodiesel Producer	Bogota
BioEnergy S.A	Bioethanol Producer	Bogota
Riopaila-Castilla S.A	Bioethanol Producer	Cali
Incauca S.A	Bioethanol Producer	Cali
Ingenio Providencia S.A	Bioethanol Producer	Cali
Ingenio Risaralda S.A	Bioethanol Producer	Pereira
Ingenio Manuelita S.A	Bioethanol Producer	Palmira
Ingenio Mayanguez S.A	Bioethanol Producer	Cali
Compañia agroporestal de Colombia S.A	Organization	Barranquilla
Ecopetrol S.A	Company	Bogota
ECI S.A	Company	Bogota
Universidad Autonoma de Colombia	Universtity	Bogota
Universidad de la Salle	Universtity	Bogota

Source: Adapted from Fedebiocombustibles (Taken on February 10, 2018)

In terms of regulations, there are various regulations including laws, decrees and resolutions promoting the integration of biofuels into the Colombian market. Law 1715 of 2014, which aims at regulating the integration of non-conventional renewable energy to the national energy system, is a governmental initiative that promotes self-generators to release to the power grid their energy surplus. This will allow, eventually, the creation of a new energy market trade-off.

For biodiesel, Resolution No. 182142 of 2007 sets the standards for the registration of producers and/or importers of biofuels for use in diesel engines and it also establishes the requirements for the mixture of biodiesel with fossil diesel. This mandate is later modified in 2018 by Resolution 40184 of 2018. Quality criteria of biofuels for diesel engines as a component of the mixture with fossil diesel fuel in combustion processes is set in Resolution No. 90963 of 2014. For bioethanol, Law 693 of 2001, sets the guidelines on the use of alcohol fuels and introduces incentives for their production, marketing and use. In 2003, Resolution 180687 issues the technical regulations for Law 693 of 2001, in which production, storage, distribution and blend mixtures of alcohol fuel is defined. In 2016, Resolution 0789 sets the parameters and quality requirements of Anhydrous Ethanol Fuel and Anhydrous Ethanol Denatured Fuel used as an oxygenating component of gasoline and other provisions are dictated.

For the inclusion of biofuels in the Colombian fuel market, the government has defined an insertion plan, which consists of a process of gradual transition, implementing changes in the regulation in blend mandates in different Colombian states. In 2018, Resolution 40185 of 2018 establishes a mixing percentage of alcohol fuel at E10 (10% fuel alcohol – 90% fossil gasoline) for regular and premium gasoline at national level. Also the Resolution No. 40184 of 2018 enacts the blend mandates at B10 (10% biodiesel– 90% fossil diesel) for diesel fuel sold in the most part of the country. Fig. 3 shows the current state of the biodiesel distribution based on the diesel blending mandate in different departments of the country.

In Fig. 3, the grey zones represent the departments with B10 coverage, and the dark zones are B2 blend. Those zones have special characteristics for being a strategic ecosystems also populated by an indigenous communities.

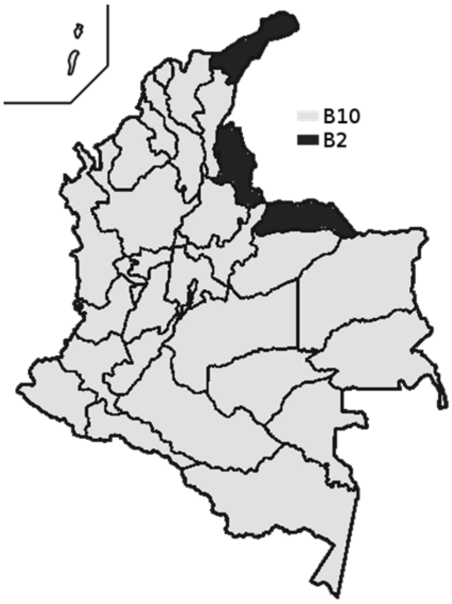

Figure. 3. Biodiesel blend distribution in Colombia Source: Adapted from fedebiocombustibles.com (Taken on March 1, 2018)

Two years ago, the Ministry of Mines and Energy of Colombia issued Resolution 240 of 2016 of the Commission for Regulation of Energy and Gas (CREG), in which the rules applicable to the public service of fuel gas with biogas and biomethane are adopted. The purpose of this regulation is to establish the quality and safety conditions, and the tariff conditions to develop the distribution channel of biogas/biomethane into the Domiciliary Public Service of Combustible Gas. Additionally, criteria related to production, transportation, distribution and marketing activities are set to be carried out only by authorized persons or enterprises considered in Article 15 of Law 142 of 1995.

In 2014, the Colombian government enacted Law 1715 of 2014. The law establishes incentives for renewable energies. In terms of generation with non-conventional energy sources (FNCE), article 6 of the law decrees that surpluses of small and large-scale self-generation are allowed to be delivered to the national interconnected system. The law establishes that CREG (Energy and Gas Regulation Commission) determines the corresponding regulation. Through Resolution UPME 281 of 2015, the limits of small scale self-generation power (AGPE) are established in 1 MW of installed capacity.

In February 2018, the Resolution CREG. 030 was issued, where the self-generation activities are regulated and the distributed generators are established as self-generators with an installed capacity of less than 0.1 MW. This resolution is a direct step towards the massification of generation with renewable energies in cities or near consumption centers. Therefore, the biofuels currently can be used in low scale generation plants as principal energy source (Sierra-Marquez, J., et al., 2017).

3.3 Quality standards of national biofuels

Quality standards in regard of biofuel blending with fossil fuels are regulated by resolutions No. 90963 of 2014 and 0789 of 2016 for biodiesel and biomethane respectively. In terms of international quality standards, the ASTM D6751-09 (American Society for Testing and Material Standard) established features criteria for biodiesel production and ASTM D 5798 for bioethanol. Brazil, Australia, and Europe also set quality criteria for the ethanol and biodiesel for fuel blending. In table 2 is shown a comparison between the named regulations for biofuel quality. In terms of detonation capacity of biodiesel, it is known that higher number of cetanes represent better quality of the fuel. Table 2 shows that the Colombian and American regulations have the same cetanes requirement, overcame by Australia and Europe in less than a 10%. All countries established water content in 500 mg/kg except Brazil which does not report data.

With a lower flash point, less energy is needed to produce combustion. Colombia and Australia has the same flash point requirement; USA has the biggest flash point allowed, which is 22% over the European flash point top. The total acid number gives an idea on the purity and corrosiveness of the biodiesel. Colombia, USA, and Europe share the lowest total acid number; it is 37% less than Australia and Brazil. It means that the biodiesel in those countries is more corrosive than Colombian, American, and European biodiesel. Before combustion process, is determined the total % in mass carbon residue. Colombia and Europe allows much more carbon residues than USA, Australia, and Brazil.

Bioethanol has a variability of 0.05% among countries. The most pure bioethanol was found in Australia and Europe, followed by Colombia and USA. The water content is inversely proportional to the energetic potential of the gasoline. Europe has the lower water content value; Colombia has water content 10% greater than Australia and a 50% lower than American limit. The density of ethanol has to be close to gasoline density for a better blending. For this parameter the difference between each reported value is less than 2%. ASTM does not report value. The copper content is an indicator of purity. Colombia, Australia, and Europe have the same maximum copper content.

Table 2. Different countries biofuel quality criteria comparison.

Parameter	Units	Region/Country				
		Colombia	ASTM (USA)	Australia	Brazil	Europe
		Bioethanol				
Appearance	visual	Clear and bright	Clear and bright	Clear and bright	Clear and bright	Clear and bright
% alcoholic at 20ºC	% mass	99,2	92,1	-	99,3	98,7
Total acidity	mass %	0,007	0,005	0,005	0,005	0,007
pHe	pH	[7, 9]	[6.5, 9]	[6.5, 9]	-	[6.5, 9]
Ethanol content	vol %	99,5	92,1	95,6	99,6	98,7
Methanol content	vol %	0,5	0,5	1	-	1
Water content	vol %	0,5	1	0,4	-	0,2
Cu content	mg/kg	0,1	0,07	0,1	0,07	0,1
Inorganic chloride content	mg/kg	10	32	1,2	-	20
Colour		Colourless	Colourless	-	Colourless or yellow	Colourless
Density	kg/m3	791,5		800	791,5	-
		Biodiesel				
Appearance	visual	Clear and bright	Clear and bright	Clear and bright	Clear and bright	Clear and bright
Cetane number	cetanes	47	47	51	45	51
Water content	mg/kg	500	500	500	-	500
Total contamination	mg/kg	24	-	24	-	24
Flash point	ºC	120	130	120	100	101
Copper corrosion	No.	1	3	3	1	1
Total acid number	mg of KOH/g	0,5	0,5	0,8	0,8	0,5
Carbon residue (100%)	% in mass	0,3	0,05	0,05	0,05	0,3
Total glycerol	% in mass	0,25	0,24	0,25	0,38	0,024
Ester content	% in mass	96,5	-	96,5	-	96,5

Colombian criteria for measurement the quality of biofuels can be compared with international quality standards, even surpassing them in some characteristics. The regulation is solid and guarantees high rank over the worldwide biofuel quality. Table 3 presents the list of biofuel quality standards considered by different countries.

4. Discussion

The Colombian fuel matrix has been principally driven by the usage of fossil carburants. Due to climate change goals and diversification of the fuel economy, efforts have been focused on the production of biofuels, mainly bioethanol and biodiesel with great share contribution in the biofuel market, in which the current demand of biofuels in Colombia is around 18.000 barrels per day (Fedebiocombustibles, 2016). There are also few cases with low energy yields reported on other renewable technologies such as anaerobic digestion, pyrolysis and gasification.

Table 3. Regulation Sources (International Fuel Quality Center, 2004) (The Netherlands Standardization Institute, 2006) (István Barabás et al. 2011) (Gerhard Knothe, 2010).

Country Biodiesel	Specifications	Title
EU	Europe normative for biodiesel 14214	European Committee for Standardization.
USA	ASTM D6751-09	American Society for Testing and Materials
Brazil	ANP 42	Brazilian Biodiesel Standard (Agência Nacional do Petróleo)
Australia	-	Australia Fuel Standard (Biodiesel) Determination 2003
Colombia	Resolution No. 90963	Ministry of Mines and Energy
Bioethanol		
Colombia	Resolution No. 0789	Ministry of Mines and Energy
EU	prEN 15376:2007	European Fuel Ethanol Specification
Brazil	ANP 19	Brazilian Anp Fuel Ethanol Specifications
Australia	Fuel Quality Standards Act 2000	Australia Fuel Standard (Ethanol) Determination 2003
USA	ASTM D 5798	American Society for Testing and Materials

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From the technical and productivity point of view, sugarcane and palm oil are the best crops to fulfil the demand of biofuels on the energy market in Colombia in which sowing is regulated and promoted by law 939 of 2004 (Marin-Burgos, V. et al., 2017). Biofuel production have demonstrated to meet existing mandatory blends. However, achieving goals of energy independence based on biofuels could entail negative impacts such as food insecurity and malnutrition for the most vulnerable population. To overcome these issues, strategic programs based on land-use and biomass availability should be structured to assist the households at major risk. However, integration of liquid biofuels into the transportation fuel market has shown promising results at reducing the dependence on fossil fuels and also mitigating the impacts of climate change.

Resolution 240 of 2016 is expected to enhance the expansion of the gas supply system and to eliminate the exclusive dependence on fossil gas. Two (2) major benefits of biogas production and utilization in Colombia are identified compared with gas derived from fossil sources: i) reduction of greenhouse gases emissions due to biogas utilization as an energy source, and ii) efficient waste management of agro-industrial residues (Rodriguez, R. et al., 2017). On the other hand, provision of the home public service of biomethane in areas interconnected to the National Transport System (SNT) can be implemented through the existent infrastructure. However, non-interconnected areas to the SNT are required to build their own infrastructure for generation, transport, commercialization and distribution of biogas.

For bioenergy integration in the energy market of Colombia, four (4) key strategies have been identified which have been already considered for the promotion of biofuels: i) constantly updated regulatory frameworks regulating biofuel blend and promoting geographical distribution on the national territory, ii) promotion of bio-based economies on rural areas in small-scale production facilities in which financial and economic incentives stated in Law 1715 of 2014 aim at enhancing the growth of the industry, iii) biomass characterization and valorization based on second generation conversion technologies to validate economic feasibility of new projects, and iv) sustainable rural development based on GIS modelling of land use and soil management. Another key opportunity for biofuels production development in Colombia stands at achieving the Millennium Development Goals (MDG) set by United Nations member states. Two main goals of the MDG related to biofuels use and production are: i) eradicate extreme poverty and hunger, and ii) ensure environmental sustainability. Biofuel use and production will provide greater energy security, new job opportunities in rural areas, and a suitable land use of abandoned soils. Additionally, biofuels resulted from crop cultivation through sustainable agricultural practices will provide economic benefits due to financial incentives promoted by national clean development mechanisms, and environmental benefits related to lower carbon emissions.

In the Colombian energy market, biofuel acceptance and penetration has important social, economic and environmental challenges that must be considered. The most important challenges identified for the biofuel market in Colombia are: land use management, feedstock availability and characterization, biofuel production prediction, environmental and health consequences, uncertainty due to climate variations, and incursion of foreign markets. Those challenges are important elements to be carefully assessed by governmental entities and different institutions to anticipate market variations to avoid economic losses.

5. Conclusions and future work

Colombian bioenergy strategies are efficiently promoting integration of different biofuels on the national energy matrix. Biorefineries are succeeding at generating liquid biofuels for its integration on the transportation fuel market with promising results at reducing the impacts of climate change and also reducing the demand on fossil fuels. Regulatory frameworks are being updated constantly enhancing biofuel mix with fossil gasoline and diesel, and extending geographical coverage in the national territory. Promotion of bio-based economies are proposed on rural energy applications on small scale ethanol and biogas production facilities. Fiscal and economic incentives are fundamental criteria to be considered to support the growth of a promising biofuels industry.

Further research is expected to forecast biomass valorisation scenarios in which studies based on second generation biomass conversion technologies are needed to validate economic feasibility of new projects of industrial facilities. Land use and soil management modelling stands as an important criteria for a sustainable rural development in which skilled personnel on GIS modelling are required. There is still lack of data, mainly on biomass characteristics and technology knowledge transfer, before considering large scale industrial facilities.

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