ANALYSIS OF SUGARCANE ETHANOL PRODUCTION FOR ENERGY DEVELOPMENT: CASE STUDY ECUADOR

GRICELDA HERRERA-FRANCO[1,2], CARLOS MORA-FRANK[1,4], GRACE ARTEAGA[3], ALBERTO LÓPEZ[3] & PAÚL CARRIÓN-MERO[4,5]
[1]Facultad de Ciencias de la Ingeniería, Universidad Estatal Península de Santa Elena, UPSE, Ecuador.
[2]Geo-Recursos y Aplicaciones, GIGA, Escuela Superior Politécnica del Litoral, ESPOL, Ecuador.
[3]Asociación de Productores de Caña de Azúcar del Cantón Milagro, APCAM, Ecuador.
[4]Centro de Investigación y Proyectos Aplicados a las Ciencias de la Tierra, CIPAT, Escuela Superior Politécnica del Litoral, ESPOL, Ecuador.
[5]Facultad de Ingeniería en Ciencias de la Tierra, FICT, Escuela Superior Politécnica del Litoral, ESPOL, Campus Gustavo Galindo, Ecuador.

ABSTRACT
The global energy issue is crucial for the development of the population and the environmental protection of the planet. The agricultural sector is part of economic, social and environmental development. However, in Ecuador, this sector has internal problems due to the suspension of the bioconversion project (e.g., ethanol production). This study aims to analyse the situation of sugarcane ethanol production in Ecuador and, through information management, to search for development strategies. The methodology includes the following: (i) sugarcane production analysis in Ecuador and ethanol distribution; (ii) policies and legal context concerning renewable energies and biofuels production in Ecuador; (iii) Political, Economic, Social, Technological, Ecological and Legal (PESTEL) as well as Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of ethanol production, based on the criteria of the experts involved and (iv) strategic guidelines for sustainable sugarcane ethanol development. Ecuador has a potential for sugarcane ethanol production that is currently not fully exploited; that is, the consumption of this resource would reduce energy demand and economic problems in the agricultural sector. Sugarcane ethanol production has generated a direct contribution to the country's Gross Domestic Product (0.5%) and a contribution to social growth (751,799 people benefited). Ethanol production could increase by 20%, generating new alternatives for biofuel consumption. This progress in Ecuador would strengthen the contribution to the Sustainable Development Goals criteria and benefit the population with new job opportunities (approximately 42,000). Therefore, the production of ethanol from sugarcane, under a legal framework, benefits economic, social and ecological relations.
Keywords: biofuels, bioethanol, Ecuador, energy development, renewable energy, sugarcane.

1 INTRODUCTION

The environmental issue is a much-discussed topic worldwide, both in developed and developing countries [1, 2]. One of the crucial initiatives by global organisations is the Sustainable Development Goals (SDGs), which set out 17 goals to protect the natural foundations of life and our planet everywhere [3]. The development of alternative sources of energy is strategic to reduce the use of fossil fuels and meet the demand in various regions, as the production of renewable energy takes place in the same area [4]. Currently, European countries and the rest of the world are implementing renewable energy as part of new economic development strategies [5, 6]. There is also growth of renewable energy production in Latin American countries, mainly hydropower (90%) and from biofuel (7%) [7]. Ecuador's energy consumption has increased in recent decades, representing 2% in Latin America. Although the country exports crude oil [8], it generates large imports of petroleum derivatives, which causes financial problems due to covering energy demand and maintaining subsidies [9]. Biofuels are an economically viable alternative to meet energy demand and contribute to reducing toxic emissions. These sources of energy have been promoted at the regional level as energy

ISSN: 2056-3272 (paper format), ISSN: 2056-3280 (online), http://www.witpress.com/journals
DOI: 10.2495/EQ-V7-N4-293-309

security tools [10]. In addition, energy from biofuels boosts the energy sector and generates economic and environmental benefits. According to Terneus and Viteri [11], 'ethanol became the ninth product with the largest amount of land suitable for agriculture, and the seventh with the most irrigated areas in a country that suffers from malnutrition'.

The country's agricultural sector also reflects a share of financial income at the national level [12]. According to a study by Alvarado Vélez *et al.* [13], during the last two decades, the agricultural sector has shown a favourable index in the country's economy, contributing directly to the Gross Domestic Product (GDP) and the industrial sector in a range of 0.6%–8%. The main crops in the agricultural area include cocoa, bananas, rice, maize, oil palm and sugarcane [14]. The latter has been seen as a possible contributor to socio-economic development in several provinces of Ecuador, like Guayas, Cañar, Los Ríos, Imbabura and Loja [15]. Ecuador processes sugarcane into derivatives for industrial and commercial consumption. Its general composition is the stalk and juice, with a chemical formulation that yields water, solids, sugars, salts, acids and non-sugars (bagasse, ash and vinasse) [16]. These natural substances are processed mainly to produce sugar and alcohol, which are used as biofuels in the country [17]. In 2013, Ecuador encouraged the biofuels market, with limited resource production, through concrete policies and planned to reduce dependence on imports [18]. As a result, the sugar mills generated sources of investment that allowed them to increase ethanol production, distributing the by-product to Petroecuador for the production of biofuels (known as Ecopaís gasoline) [11]. In 2018, the Ecuadorian government limited the purchase of ethanol from local industries, affecting the agricultural economy. This government decision is due to the price variation of ethanol to generate economic savings for the state [19]. However, the contracted company continued its purchases from the sugarcane growers in the following months until 2020, as the COVID-19 pandemic affected the local economy, causing a reduction in the use of this resource.

In Ecuador, ethanol production generates socio-economic opportunities in several provinces. For example, Pacheco *et al.* [20] analysed the relationship between economic growth and the agricultural production structure. This study indicates that, although the provinces of Pichincha (1.91) and Guayas (1.69) have a high Gross Value Added in the agricultural sector, they do not exceed the median of 2.14, with strategic development being significant.

During the last decades, the Ecuadorian government implemented policies to promote the development of renewable energies, which did not have the expected results [21]. The Republic's Constitution of 1998 established initiatives in using renewable energy. However, the 2008 Constitution strengthened this principle by integrating the concept of energy efficiency [22], by, for instance, incorporating vehicles benefiting from an electricity system and preferential energy tariffs [23].

This research shows the energy and economic potential that the country could achieve with a favourable use of its natural resources. However, such projects require participatory and interactive models to understand the problems and generate solutions [24, 25]. This context raises some questions as follows: How could sugarcane ethanol production increase to generate a socio-economic impact in the rural sectors of Ecuador's provinces? and How to build a set of participatory policy strategies for increased sugarcane ethanol production that strengthen the renewable energy framework?

This paper aims to analyse the situation of sugarcane ethanol production in Ecuador, using information from published and shared data, and to search for strategies to strengthen the country's economic development.

2 METHODOLOGY

The present research comprises four phases (Fig. 1): (i) sugarcane production analyses in Ecuador and ethanol distribution through the use of published information and participating entities; (ii) analysis of the legal information related to renewable energy and biofuels (ethanol production and legalisation of prices); (iii) Political, Economic, Social, Technological, Ecological and Legal (PESTEL) as well as Strengths, Weaknesses, Opportunities and Threats (SWOT) analyses and (iv) adopting strategic guidelines for sustainable development of sugarcane ethanol.

2.1 Phase I: General information

This section consists of information on the status of ethanol concerning agricultural production and its blending with gasoline, as well as regional analysis and benefits; more specifically, the current production of the 10 main products of the primary sector, biofuel production (Ecopaís gasoline), regional and global levels, as well as benefits of sugarcane ethanol

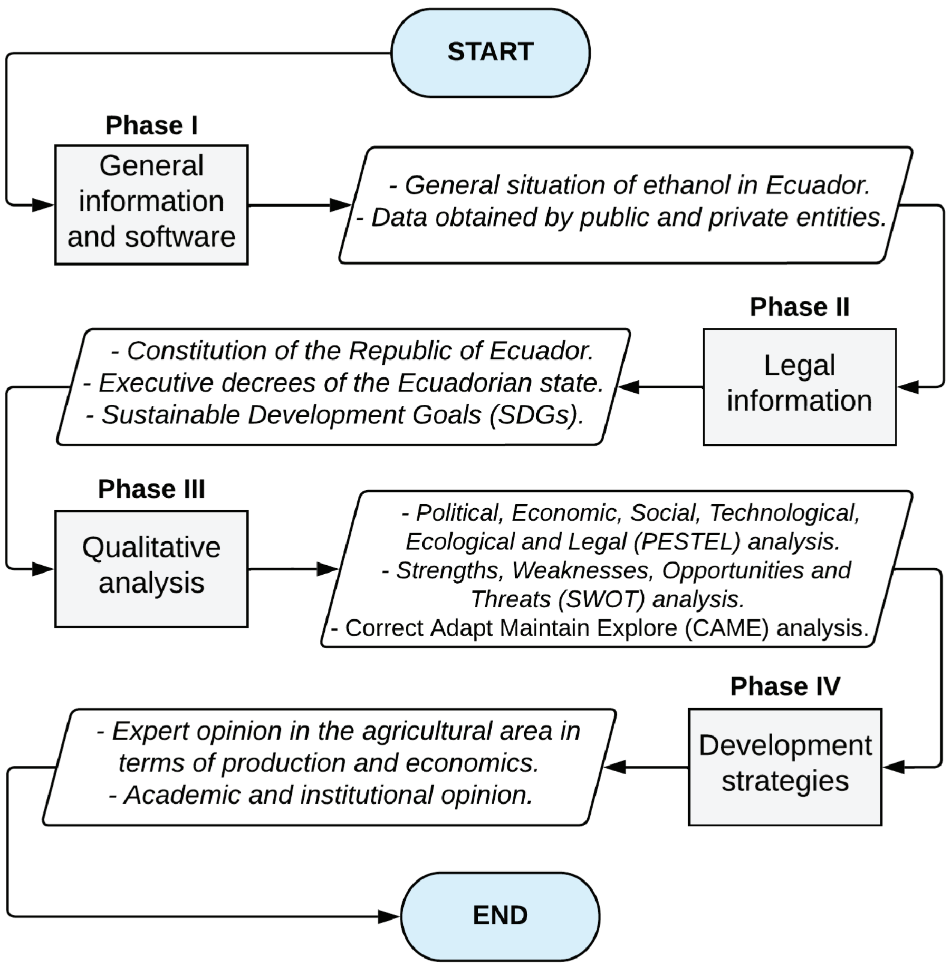

Figure 1: Methodological outline of the research.

production. This information generates a scientific structure that will support the criteria for analyses of socio-economic development strategies. The compilation consisted of a scientific search in major academic databases such as Google Scholar, Latindex, Scopus and Web of Science. On the other hand, additional data were obtained from the Asociación de Productores de Caña de Azúcar del Cantón Milagro (APCAM) and Asociación de Biocombustibles del Ecuador (APALE), through presentations and conferences. In addition, information from national and international websites was used, such as the Ministerio de Agricultura y Ganadería (MAG) [26], Instituto Nacional de Estadística y Censos (INEC), Sistema de Información Pública Agropecuaria (SIPA) [14], Petroecuador Public Company [27] and S&P Global Platts [28]. This study used Microsoft Excel and ArcGIS software for data generation. Excel managed the collected data using intermediate level functions to generate pivot tables, static tables and hyperlinks. In ArcGIS, a regional map was constructed to compare the production and consumption of ethanol in blends with gasoline for biofuel.

2.2 Phase II: Legal information

This second phase showcased the Ecuadorian state's policy information related to the renewable energy framework. Therefore, some articles of Ecuador Republic's Constitution of 2008 (articles 15, 335, 413 and 414) [29,30], executive decrees (Decrees No. 1303, 675 and 1183) [31, 32] and the SDGs related to energy and the environment (goals 7 and 13) were detailed [3].

2.3 Phase III: Qualitative analysis

The third phase consisted in carrying out, in the first stage, a PESTEL analysis for the strategic, organisational and market planning of the company [33]. The development consisted of analysing each variable according to the experience of experts in the agriculture area for strategic planning [34]. This approach identified and analysed factors associated with economic-environmental development, including future activity in the agricultural/energy area, the socio-cultural part, the influence of new technologies and the future change in Ecuador's political regulations. Overall, this analysis allowed for an assessment of the outlook, growth and direction of the organisation's operations and the external elements that may affect the agricultural and industrial systems. In a second stage, according to the criteria generated in PESTEL, a SWOT analysis [35] was carried out for the development of a qualitative assessment, formulating strategies on external and internal factors [36]. Experts carried out this analysis in the sugarcane production area to generate development strategies within an economic, social and environmental framework. This analysis provided an overview of the status of ethanol production and use. Finally, a Correct Adapt Maintain Explore (CAME) analysis was generated based on the results obtained by SWOT [37]. In general, the unanimous opinion of APALE and APCAM members was considered in the three analyses, strengthening the criteria with publications indexed in databases.

2.4 Phase IV: Development strategies

The fourth phase generated socio-economic development and environmental protection strategies, through the results of the CAME analysis, for the strengthening of sugarcane ethanol production. This content was developed through the opinion of experts related to the area of study, providing a scientific content of qualitative context for the social and academic community. Experts devised strategies that solve problems and transform current needs.

3 RESULTS

3.1 General information

3.1.1 Main agricultural products in Ecuador

Ecuador has a sizeable territorial extension destined to agriculture to harvest staple products (2,240,918 hectares [ha]). The sugarcane plantation consists of 110,000 ha (55% belonging to 5,000 independent cane growers and 45% to the sugar mills), where 70,000 ha belong to sugar production (63.6%) and 22,000 ha (20%) to ethanol production. The difference is in the production of alcoholic beverages and panela. The production has 44% of sugarcane growers concentrated in the coastal and highland regions, mainly in the provinces of Guayas (76%), Cañar (12%), Loja (6%), Imbabura (4%) and Los Ríos (2%). Ecuador's three most representative sugar mills have alcohol distilleries (i.e., San Carlos, Soderal, Valdez, Codana, Coazucar and Producargo), aggregated as the Association of Biofuels of Ecuador (APALE). This partnership produces 95 million litres of ethanol per year (598,500 barrels).

3.1.2 Production of biofuel (Ecopaís gasoline)

Since 2018, there has been significant growth in the production of Ecopaís gasoline in Ecuador (Table 1). According to Petroecuador industry data, Ecopaís gasoline production had an important quality index for industrial and urban consumption. On the other hand, Petroecuador figures show that ethanol has varied participation in gasoline blends, with a range of 145.2–409.8 k barrels of ethanol, where the legal mix is 5% ethanol and 95% gasoline (62% high octane naphtha [HON] and 33% low octane naphtha [LON]) [38]. However, the figures show percentages below 5% since 2017 (2.9%), with 2021 being the year with the lowest rate of ethanol in gasoline blends (1.57%).

Table 1: Ecopaís gasoline blending and production during the last 6 years based on [27].

	ECOPAIS gasoline (figures in barrels)				
Years	**Terminals**	**Premix**	**Ethanol**	**% Ethanol**	**Total mixes**
2016	Pascuales, La Toma-Loja	4,829,854	215,620	4.46	5,174,984
2017	Pascuales, La Toma-Loja, Barbasquillo-Manta, Cuenca, La Troncal	4,942,107	145,292	2.94	21,930,105
2018	Pascuales, La Toma-Loja, Barbasquillo-Manta, Cuenca, La Troncal	12,116,397	351,376	3.00	22,141,109
2019	Pascuales, La Toma-Loja, Barbasquillo-Manta, Cuenca, La Troncal	12,859,863	409,850	3.19	21,263,512
2020	Pascuales, La Toma-Loja, Barbasquillo-Manta, Cuenca, La Troncal	9,106,052	193,289	2.12	15,268,464
2021	Pascuales, La Toma-Loja, Barbasquillo-Manta, Cuenca, La Troncal	5,679,136	152,303	1.57	9,681,296

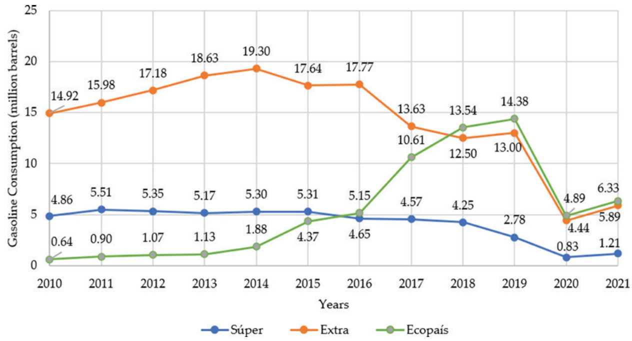

Figure 2: Consumption of the main gasolines in Ecuador (2010–2019) based on [27].

3.1.3 Gasoline consumption in Ecuador

Regarding gasoline consumption (Fig. 2), in April 2012, the Ecuadorian state announced measures to improve the quality of Extra and Ecopaís gasoline to 87 octanes. The increase in the octane rating of these two gasoline types led to lower consumption of Super gasoline, which had improved from 90 to 92 octane, between 2012 and 2018. As a result, Super gasoline had monthly updates in its consumer prices, reaching 2.98 USD in 2017, while Extra and Ecopaís went from 1.48 to 1.85 USD. These price changes and the country's economic problems have led the population to consume more gasoline with lower prices and improved octane levels (Extra and Ecopaís). Therefore, between 2020 and 2021, Extra and Ecopaís gasoline consumption fell by 66% and Super gasoline by 70% due to the COVID-19 pandemic.

3.1.4 Regional ethanol production and consumption

In six countries in the region, there is a participation of ethanol in gasoline blends, with Brazil leading the way with a significant amount of biofuel production and consumption (Fig. 3) [39]. Other countries show lower participation in biofuels, with ethanol percentages ranging from 5% to 25%, like Argentina, Colombia, Ecuador and Paraguay [28]. However, four other nations do not show participation. In local terms, Ecuador has an essential consumption in the region using this innovation as an alternative energy source.

3.1.5 Benefits of ethanol to the environment

The data reaffirm that sugarcane ethanol for gasoline production is the best way to contribute to an ecological transition [40]. In addition, the world's leading countries regarding environmental protection and the impulse of resource regenerative processes use these measures as measurable parameters within their public policies. Overall, sugarcane shows a significant energy ratio to other agricultural commodities [41, 42]. Their contribution to the fossil energy mix is essential for reducing greenhouse gas emissions [43].

3.1.6 Benefits of ethanol production in the region

By increasing ethanol production, Ecuador can contribute to the region's economic, social and environmental development (Table 2). First, regarding economic benefits, it would reduce the migration of Ecuadorians from rural areas to countries with job opportunities. In addition, the export of ethanol would benefit the use of alternative energy sources in countries that do not have biofuel production and consumption. Second, regarding social

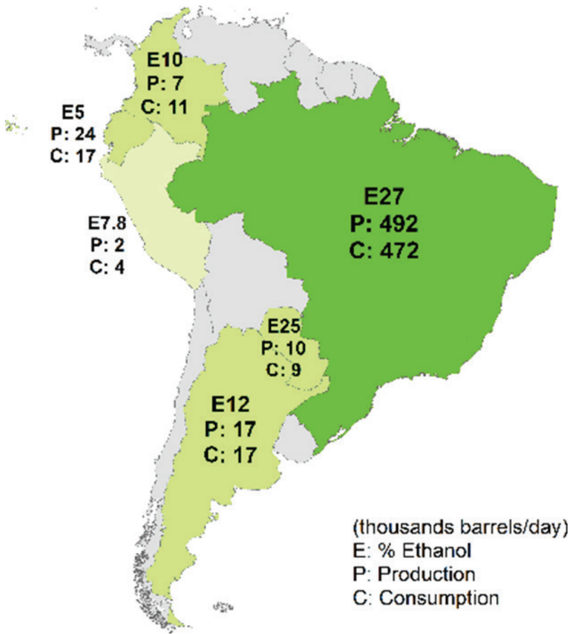

Figure 3: Production and consumption of ethanol as a fuel based on [28].

Table 2: Ecuador's contribution to the region.

Aspects	**Categories**	**Description**	**Countries involved**
Economic	International migration	Reducing rural migration of Ecuadorians in search of opportunities.	Brazil, Chile, Peru
	Trade	Exporting sugarcane ethanol for biofuel use.	Bolivia, Venezuela, Chile, Uruguay
Social	Labour contribution	Job opportunities to national and foreign persons through the growth of the agricultural sector in ethanol.	Venezuela
Environmental	Emission	Reduction of pollution to related flora and fauna, such as the Amazon and Pacific Ocean (Ecuador-Colombia; Ecuador-Peru).	Colombia, Perú
	SDGs	Strengthening the international goals for sustainable development.	All region

benefits, it would represent an economic contribution to foreign migrants coming from countries with severe economic crises (e.g., Venezuela). Third, concerning the environment, the consumption of sugarcane ethanol reduces pollution of flora and fauna in vulnerable areas, like the Amazon (local and migratory species) and marine ecosystems (23% of biofuel in fleets).

3.2 Legal information

3.2.1 Ecuador Republic's constitution

Ecuador's constitution, published in the Official Register 449 of 20 October 2008 [29], promotes the use of renewable technologies and energy. This information impacted alternative energy innovation, both in industry and academia. The following articles answer the various criticisms a National Assembly has on renewable energy: articles 15, 335, 413 and 414. Based on the legal framework of the Constitution of the Republic of Ecuador, the Código Orgánico de la Producción, Comercio e Inversiones (according to Spanish) [30] was created. This registry proposes to boost the industrial and commercial system in the exports and imports generated by Ecuador.

3.2.2 Executive decrees

Executive Decree No. 1303, published in the supplement to Registro Oficial No. 799 of 28 September 2012, declares interest in developing biofuels (Ecopaís gasoline). In addition, the information refers to the introduction of Ecopaís gasoline, indicating that it is a biofuel made from renewable raw materials, such as sugarcane. It also mentions that sugarcane ethanol can be used as an additive and blending component in preparing domestically marketed gasoline.

On the other hand, Executive Decree No. 675 with Official Register No. 512, published on 1 June 2015 [31], regulates the price per litre of alcohol considering the cost of national alcohol production and the opportunity cost of producing extra gasoline. It also determines the percentage of ethanol used in blends with conventional gasoline to produce Ecopaís; e.g., articles 1, 3, 4 and 5.

The Agency sets fuel prices in Ecuador for Agencia de Regulación y Control de Energía y Recursos Naturales No Renovables (ARC). This agency determines fuel prices (Extra, Ecopaís and diesel) through executive Decree No. 1183, published in November 2020, for the supply and commercialisation of the resource [32].

3.2.3 Sustainable Development Goals

On 25 September 2015, the world's leading countries promoted a set of global goals, designated as SDGs [3], aimed at eradicating poverty, protecting the planet and ensuring prosperity for all, which would form part of a new sustainable development agenda. These objectives have specific targets with a scope of 15 years from their approval (2015). The SDGs consist of 17 goals, and this theme is related to goals 7 (Affordable and Clean Energy) and 13 (Climate Action). The innovation of ethanol for blending with gasoline has a favourable 'energy intensity ratio' performance, making it a clean resource relative to conventional gasoline (100% petroleum-derived). In addition, these results guarantee the environmental protection in using these biofuels, contributing to the climate change balance that the world is currently experiencing.

3.3 PESTEL and SWOT analyses

3.3.1 PESTEL analysis

This analysis provided an overview of the current situation in the agricultural sector in the production of sugarcane ethanol (Table 3).

In Ecuador, there is no policy regarding the agricultural sector, with stagnant programmes that generate major financial problems for sugarcane ethanol producers. Petrocomercial's

Table 3: PESTEL analysis of sugarcane ethanol production based on [11, 15, 44] and entities (APCAM and APALE).

Political	(i) Ethanol production programme not met (contracts in place between Petrocomercial company and sugarcane ethanol producers); (ii) Lack of state policy for the development of the agricultural sector; (iii) There is no regulator to protect the agricultural producer; (iv) Ministerial agreements are not complied with; (v) Ecuador is not aligned to the global policies of the SDGs.
Economic	(i) Direct contribution to Gross Domestic Product (GDP) (0.5%); (ii) Savings in foreign exchange outflows with the use of ethanol (100 million USD); (iii) The programme generates new sources of employment (208,833); (iv) With the increase in the percentage of ethanol in blends, it is necessary to expand the existing agricultural frontier; (v) There is the possibility of increasing the percentage of ethanol use to 20% without modifying vehicle engines; (vi) There is a large public and private investment to develop the ethanol programme with the capacity to grow; (vii) Ecopaís gasoline is the most in-demand nationally.
Social	(i) The sugarcane and ethanol production chain has benefited 751,799 people, who are currently experiencing instability due to the stagnation of the ethanol programme; (ii) 5,000 sugarcane growers depend on ethanol production; (iii) Lack of socialisation and promotion of the ethanol production programme relevance; (iv) Ethanol production contributes to the non-migration of rural sectors.
Technological	(i) Ecopaís gasoline is a quality product at a low price; (ii) Ethanol is a renewable energy source; (iii) Sugarcane is the most energy-efficient plant for ethanol production; (iv) Ethanol improves octane in the blend with low octane naphthas; (v) The country has privileged conditions for the development of sugarcane cultivation; (vi) The crop has a high level of mechanisation; (vii) The "Centro de Investigación de la Caña de Azúcar del Ecuador (CINCAE)" contributes to researching new technologies and varieties of sugarcane; (viii) Sugarcane production generates derivatives and by-products that have economic value.
Ecological	(i) Ethanol is a clean energy source; (ii) Its use reduces 89% of greenhouse gas emissions (CO_2) relative to other agricultural products; (iii) Ethanol use is key to public health and the environment; (iv) Ethanol does not generate toxic and unhealthy elements; (v) Biofuel production represents an alternative to the use of fossil fuels.
Legal	(i) There are unfulfilled state ethanol purchase contracts (less than 4% in blends since 2017); (ii) Need for a biofuel law; (iii) Enforcement of laws to prevent speculation and monopolistic practices in agricultural marketing.

contracts with government entities do not always comply with the agreement, according to the criteria of some focus group members in the SWOT analysis. A state policy is a current necessity for sector development. Ethanol production is an available energy source that would significantly benefit the state and the business relationship. Among the main ones are job opportunities, direct contribution to the GDP, volumetric support to the current demand for Ecopaís gasoline production and savings in foreign currency outflows (100 million USD).

Over the last 10 years, the sugarcane and ethanol production sector has generated jobs in urban and rural areas, which are at serious risk due to the stagnation of the ethanol programme. The socialisation and promotion strategy of the importance of the ethanol production programme will make it possible to develop a sustainable socio-economic-industrial system involving the primary sectors (producer, industry and trade). It is essential to mention that the relationship between economic growth and environmental protection in the 21st century has become an issue of great importance, and Ecuador has low participation in the SDGs. Biofuels used in the country are an alternative to replace fossil fuels in the transport sector, stationary engines and greater energy sustainability (objective 7).

3.3.2 SWOT analysis

The SWOT analysis (Table 4) considered the criteria mentioned in the earlier PESTEL analysis. The analysis revealed that Ecuador could produce large quantities of ethanol through increased land to produce and harvest sugarcane. However, the country currently has weaknesses in ethanol production, such as lack of biofuels legislation and national promotion. Furthermore, the low efficiency of producers in discounts and incidental charges for not paying their crops on time has resulted in a severe crisis in this agricultural sector. Therefore, a lack of primary sector protection in a framework of economic-industrial development is determined. On the other hand, some threats would affect the industrial and social (rural) economy, causing internal (unemployment) and external (protests to the state) problems in vulnerable sectors.

3.3.3 CAME analysis

Table 5 shows the CAME analysis that is considered through the SWOT results to support the generation of socio-economic and environmental development strategies.

3.4 Development strategies

Strategies implemented include the following: (i) Design a social-economic policy considering sugarcane production and its connection through clean production with national and international cooperation funds to preserve the planet; (ii) Implement a state policy that protects the employment status of 5,000 national sugarcane growers, as they depend on producing this raw material, allowing them to achieve social development; (iii) Generation of clean energy through biofuel (ethanol based on sugarcane) to counteract the pollution generated by fossil energy, considering the principles of the global strategy of the SDGs; (iv) Development of an incentive policy for biofuel production that supports the most energy-efficient agricultural products with a growth horizon of 2025–2030; (v) Regulation, control and development of the entire biofuels production system from the agricultural production phase, through industrialisation to marketing, making it a system conducive to sustainable development; (vi) Implementation of a policy that promotes sugarcane ethanol through developing a biofuel law to reduce HON imports; (vii) Generate a legal framework that guarantees sustainable sugarcane production and prohibits the import of ethanol to encourage national production and contribute to GDP; (viii) Establish a strategy to promote environmental education for biofuel with Ecuadorian products that strengthen sustainable development.

4 DISCUSSION

Ecuador uses large tracts of land to harvest sugarcane, with 20% destined for ethanol production. However, the lack of strategies that induce a state policy limits the development and empowerment of this primary sector. One of the sources of the sector's problems is the inaction of the regulatory bodies, which, despite pressure from interest groups, demonstrate a

Table 4: SWOT analysis of sugarcane ethanol production based on [11] and entities (APALE and APCAM).

Internal factors / External factors	**Strengths**	**Weaknesses**
	1. Sugarcane ethanol production capacity. 2. There are tracts of land available for cultivation. 3. Ethanol is a clean energy source, being a non-toxic product concerning methanol or other alcohols.	1. Lack of legislation related to biofuels and ethanol promotion. 2. There is no formula to relate the price per metric tonne that receives the producer to ethanol cost. 3. Lack of protection for the primary sector. 4. Lack of legal framework.
Opportunities	**Strengths + Opportunities**	**Weaknesses + Opportunities**
a. New national government. b. Real opportunities for employment generation in sugarcane production. c. There is a public and private investment for installed capacity. d. Take advantage of the global trend of replacing fossil fuels with alternative energies (ethanol). e. The use of ethanol would generate compliance with the international goals (SDGs). f. 89% emissions reduction relative to other agricultural commodities.	1.a. Energy development through the support of the new government regime. 1.2.b.c. Entity linkages and state investment to boost the social and industrial economy. 3.d.f. Reducing environmental pollution in vulnerable areas, with international cooperation funds.	1.a.d. Legal decree to promote the use of ethanol-based biofuel as renewable energy. 3.4.a. Regulatory law with long-term goals to protect ethanol production. 2.3.a.c. Strategic planning for ethanol trade control. 4.e. Legal framework in harmony with the SDGs for ethanol production.
Threats	**Strengths + Threats**	**Weaknesses + Threats**
a. Lack of gasoline imports regulation. b. Legal Decree No. 1158 allows free import of naphtha.	1.a.b. Increased percentage of ethanol in gasoline blends for LON imports reduction.	2.a. Legislation regulating the internal trade of ethanol in its production, sale and consumption. 1.4.b. Adjustments to Decree No. 1158 reducing the free import of naphtha and promoting the use of ethanol.

Table 5: CAME analysis based on APALE and APCAM.

Maintain	Correct
– Avoid the reduction of land destined for sugarcane production. – Maintaining sugarcane production for biofuels. – Ethanol is a priority for environmental and economic benefit.	– Promoting biofuel consumption through a legal decree. – Generate control in the distribution centres for the purchase and sale of ethanol. – Government intervention in the agricultural sector to strengthen productive security.
Explore	**Adapt**
– Leveraging the new governorates with innovative projects. – Implementing a strategic framework through investment for social development. – Strengthen the concept of the SDGs through ethanol production as the main biofuel in blended and unblended.	– Reducing gasoline imports through the energy benefits of ethanol. – Generate a reform that benefits ethanol producers, whether for biofuel consumption or other resources.

weak policy of laws and regulations, creating a political absence and monopolies. Therefore, the state entity can generate a legal framework that regulates the internal commercialisation processes, such as the costs of production and sale to the target sector. Furthermore, according to Petroecuador's technical reports [27], since 2017, ethanol has had a share of between 1% and 3% in blends with gasoline, resulting a legal non-compliance related to the percentage of the contract established (5% ethanol and 95% gasoline [38]).

The presence of legal regulation would benefit the economic system of the sugar industries, from the various sugarcane producers, the industry and marketing, as there would be a reduction of overpricing and control on contract purchases. In Ecuador, there is a relevant production of ethanol (119,700 barrels), destined for biofuel energy consumption, and the availability of sugarcane production (11 million tonnes) to increase the percentage of ethanol in blends to 10%. Furthermore, there is the possibility of increasing the use of ethanol to 20%, which would mean saving foreign exchange relative to the import of HON and notional derivatives, like LON.

The sugar industry and its related sectors have benefited around 751,799 people. Interest in converting other farmland to sugarcane and ethanol production would recruit new sugarcane growers, offering labour sustainability. On the other hand, the intervention of a state policy is necessary to protect the sugarcane growers and their social development, as financial problems generate non-payments to the producers by the industry and the price imbalance in the production and trade sector. As a result, the increase of a liquidity crisis in the industry would affect the entire production chain, as well as social relations (direct and indirect) and sugarcane growers (artisanal and independent) [45].

The sugarcane industry is one of the world's largest biofuels producers [41]. This resource has a chemical composition of interest, as it has bagasse and residues used as fuel sources [46]. In addition, they are derivatives with a high energy content due to their high amounts of carbon, hydrogen, oxygen and ash (99%) and a lower proportion of sulphur and nitrogen (1%). As a result, this product has a significant energy efficiency of 9.3 MJ/kg, relative to other agricultural products, like maize (0.2–0.6 MJ), wheat (0.97–1.11 MJ), beetroot (1.2–1.8 MJ), cassava (1.6–0.7 MJ) and lignocellulosic residues (8.3–8.4 MJ) [42,47]. Therefore, sugarcane under the thermal intervention process is self-sufficient for biofuel use [41].

Ecuador has a natural diversity that places it among the 17 megadiverse countries in the world, hosting a variety of birds (16%), amphibians and mammals (8%), and reptiles (5%). This potential gives the country a solid link to the SDGs. Thus, biofuels (e.g., ethanol used for gasoline) are clean energy sources that reduce environmental pollution in areas of high vulnerability [48]. For example, it is possible to reduce CO_2 emissions through ethanol consumption blended with gasoline for urban and industrial transport use within the overall framework of sustainable development [43, 49]. Therefore, in achieving the SDGs, ethanol in gasoline is expected to play a crucial role in protecting the environment, becoming an essential source of biofuels for sustainable purposes. In general terms, sugarcane ethanol as a biofuel would benefit the relationship between economic-industrial, social and environmental growth in Ecuador and the region.

5 CONCLUSIONS

In Ecuador, there are privileged agro-ecological conditions for sugarcane ethanol production, which is an excellent opportunity to reactivate agricultural production and a viable option to alleviate the crisis in the sugarcane sector. Although ethanol production in Ecuador is not relevant at present, there is the capacity to take substantial advantage of this resource, allowing the promotion of green transport through industrial, academic, and scientific contributions. In addition, the ethanol used as the primary fuel would reduce the energy demand for fuels and the economic problems of the agricultural sector. Overall, Ecuador could increase ethanol production by 20% as a new energy consumption alternative, replacing imports of petroleum derivatives. This development benefits the social, industrial and productive sectors by developing new employment opportunities (approximately 42,000). On the other hand, in Ecuador, the issue of fuel consumption and environmental protection is not in line with international goals (i.e., SDGs) that strategically promote a sustainable development framework. The analysis shows that objectives 7 and 13 align with the innovation on the use of sugarcane ethanol (Ecopaís gasoline), as it is friendly energy concerning conventional gasoline and, as a result, the reduction of greenhouse gas emissions (CO_2). Development strategies in the agricultural sector are of great importance to (i) reduction of CO_2 emissions to 10% ethanol in blends, contributing to the protection of the environment in the framework of the SDGs; (ii) biofuels will continue to be a pivotal solution to decarbonise vehicle transport in the coming years in Ecuador and the region due to the increasing interest in this alternative energy; (iii) diversification and innovation in the growth of biofuels are needed, as this would avoid the imbalance of feedstocks destined for ethanol production in Ecuador and the region.

ACKNOWLEDGEMENTS

This work had the collaboration of several business associations, such as the Asociación de Productores de Caña de Azúcar del Cantón Milagro (APCAM) and the Asociación de Biocombustibles del Ecuador (APALE). Alejandro Gallardo and Orlando Zambrano participated in APCAM. In APALE, Gustavo Heinert (president) and Carlos León (analyst) participated. In addition, had the collaboration to project of the ESPOL Polytechnic University such as "Registry of geological and mining heritage and its impact on the defence and preservation of geodiversity in Ecuador" with code CIPAT-01-2018.

REFERENCES

[1] Rahman, M. M. & Alam, K., Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. *Renewable Energy*, **172**, pp. 1063–1072, 2021. https://doi.org/10.1016/j.renene.2021.03.103

[2] Herrera-Franco, G., Montalván-Burbano, N., Mora-Frank, C. & Moreno-Alcívar, L., Research in petroleum and environment: A bibliometric analysis in South America. *International Journal of Sustainable Development & Planning*, **16(6)**, pp. 1109–1116, 2021. https://doi.org/10.18280/ijsdp.160612

[3] The Global Goals, *The Global Goals for Sustainable Development*, 2015. https://www.globalgoals.org/. Accessed on: Oct. 25, 2021

[4] Østergaard, P. A., Duic, N., Noorollahi, Y., Mikulcic, H. & Kalogirou, S., Sustainable development using renewable energy technology. *Renewable Energy*, **146**, pp. 2430–2437, 2020. https://doi.org/10.1016/j.renene.2019.08.094

[5] Ntanos, S., *et al.*, Renewable energy and economic growth: Evidence from European countries. *Sustainability*, **10(8)**, p. 2626, 2018. https://doi.org/10.3390/su10082626

[6] Herrera-Franco, G., Erazo, K., Mora-Frank, C., Carrión-Mero, P. & Berrezueta, E., Evaluation of a paleontological museum as geosite and base for geotourism. A case study. *Heritage*, **4(3)**, pp. 1208–1227, 2021. https://doi.org/10.3390/heritage4030067

[7] Koengkan, M., Poveda, Y. E. & Fuinhas, J. A., Globalisation as a motor of renewable energy development in Latin America countries. *GeoJournal*, **85(6)**, pp. 1591–1602, 2020. https://doi.org/10.1007/s10708-019-10042-0

[8] Herrera-Franco, G., Escandón-Panchana, P., Erazo, K., Mora-Frank, C. & Berrezueta, E., Geoenvironmental analysis of oil extraction activities in urban and rural zones of Santa Elena Province, Ecuador. *International Journal of Energy Production & Management*, **6(3)**, pp. 211–228, 2021. https://doi.org/10.2495/EQ-V6-N3-211-228

[9] Pinzón, K., Dynamics between energy consumption and economic growth in Ecuador: A granger causality analysis. *Economic Analysis & Policy*, **57**, pp. 88–101, 2018. https://doi.org/10.1016/j.eap.2017.09.004

[10] FAO, *La Bioenergía en América Latina y El Caribe. El estado de arte en países seleccionados*, Santiago, Chile: Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO), 2013.

[11] Terneus Páez, C.F. & Viteri Salazar, O., Analysis of biofuel production in Ecuador from the perspective of the water-food-energy nexus. *Energy Policy*, **157**, 112496, 2021. https://doi.org/10.1016/j.enpol.2021.112496

[12] Pasqual, J. C., Lardizabal, C. C., Herrera, G., Bollmann, H. A. & Nunes, E. O., Water-energy-food nexus: Comparative scenarios and public policy perspectives from some Latin American countries regarding biogas from agriculture and livestock. *Journal of Agricultural Science & Technology A*, **5(6)**, pp. 408–427, 2015. https://doi.org/10.17265/2161-6256/2015.06.004

[13] Alvarado Vélez, J. A., Vélez Bravo, G. P. & Mila Carvajal, F., El sector primario: ¿Contribuye al crecimiento económico del Ecuador?. *Rev. Hallazgoz21*, **2(2)**, pp. 158–167, 2017.

[14] Cifras Agroproductivas, *Sistema de Información Pública Agropecuaria*, 2020. http://sipa.agricultura.gob.ec/index.php/cifras-agroproductivas (accessed Oct. 26, 2021).

[15] Paguay García, M. V., Evaluación de riesgos laborales en la producción de alcohol destilado de la caña de azúcar en Ecuador, Universidad Politécnica de Valencia, 2016.

[16] CINCAE, Utilización de subproductos de la caña de azúcar y de la industria alcoholera ecuatoriana para uso en la fertilización en los cultivos de caña, *Centro de Investigación de la Caña de Azúcar del Ecuador (CINCAE)*, 2013. https://cincae.org/utilizacion-de-subproductos-de-la-cana-de-azucar-y-de-la-industria-alcoholera-ecuatoriana-para-uso-en-la-fertilizacion-en-los-cultivos-de-cana/
[17] Ministerio de Agricultura y Ganadería, Ecuador marca su rumbo en la industria de los agrocombustibles, 2019. https://www.agricultura.gob.ec/ecuador-marca-su-rumbo-en-la-industria-de-los-agrocombustibles/
[18] Polanco Pacheco, C.A., Optimum technology network for ethanol production and electricity cogeneration in Ecuador, University of Twente (UT), 2016.
[19] Martínez Olaya, H.E., Análisis del uso de biocombustibles en Ecuador periodo 2010–2017, Universidad Católica de Santiago de Guayaquil, 2018.
[20] Pacheco, J., Ochoa-Moreno, W.-S., Ordoñez, J. & Izquierdo-Montoya, L., Agricultural diversification and economic growth in Ecuador. *Sustainability*, **10(7)**, p. 2257, 2018. https://doi.org/10.3390/su10072257
[21] Arroyo, F. R. & Miguel, L. J., The role of renewable energies for the sustainable energy governance and environmental policies for the mitigation of climate change in Ecuador. *Energies*, **13(15)**, p. 3883, 2020. https://doi.org/10.3390/en13153883
[22] Pelaez, M. & Espinoza, J., *Energías renovables en el Ecuador: situación actual, tendencias y perspectivas*. Cuenca, Ecuador: Universidad de Cuenca, 2015.
[23] Icaza, D. & Borge-Diez, D., Potential sources of renewable energy for the energy supply in the city of Cuenca-Ecuador with towards a smart grid. *8th International Conference on Renewable Energy Research and Applications (ICRERA)*, pp. 603–610, 2019.
[24] Herrera-Franco, G., Carrión-Mero, P. & Alvarado M., N., *Participatory process for local development: Sustainability of water resources in rural communities: Case Manglaralto-Santa Elena*, Ecuador, pp. 663–676, 2018.
[25] Herrera-Franco, G., Gavín-Quinchuelaa, T., Alvarado-Macancela, N. & Carrión-Mero, P., Participative analysis of socio-ecological dynamics and interactions. A case study of the Manglaralto Coastal Aquifer, Santa Elena-Ecuador. *Malaysian Journal of Sustainable Agriculture*, **1(1)**, pp. 19–22, 2017. https://doi.org/10.26480/mjsa.01.2017.19.22
[26] MAG, Sector Cañicultor y acciones del Ministerio de Agricultura, *Ministerio de Agricultura y Ganadería (MAG)*, 2019. https://www.agricultura.gob.ec/sector-canicultor-y-acciones-del-ministerio-de-agricultura/ Accessed on: Nov. 15, 2021.
[27] EP Petroecuador, Cifras Institucionales, *Empresa Pública Petroecuador*, 2021. https://www.eppetroecuador.ec/?p=3721. Accessed on: Nov. 15, 2021.
[28] S&P Global Platts, *S&P Global Platts*. https://www.spglobal.com/platts/es. Accessed on: Dec. 10, 2021.
[29] Asamblea Nacional del Ecuador, Constitución de la República del Ecuador, Quito-Ecuador, 449, 2008. https://www.defensa.gob.ec/wp-content/uploads/downloads/2021/02/Constitucion-de-la-Republica-del-Ecuador_act_ene-2021.pdf
[30] Asamblea Nacional del Ecuador, Código Orgánico de la Producción, Comercio e Inversiones, COPCI, Quito, Ecuador, 351, 2010. https://www.correosdelecuador.gob.ec/wp-content/uploads/downloads/2018/11/COPCI.pdf
[31] Presidente Constitucional de la República, Decreto No. 675, Quito, Ecuador, 675, 2015. https://www.controlhidrocarburos.gob.ec/wp-content/uploads/2018/09/COMPOSICIÓN-DISTRIBUCIÓN-Y-COMERCIALIZACIÓN-DE-GASOLINA-ECOPAÍS-FIEL.pdf

[32] Presidente Constitucional de la República, Decreto ejecutivo No. 1183, Guayaquil, Ecuador, 1183, 2020. https://www.fielweb.com/App_Themes/InformacionInteres/Decreto_Ejecutivo_No._1183_20201004065505_20201004065525.pdf

[33] Dale, C., The UK tour-operating industry: A competitive analysis. *Journal of Vacation Marketing*, **6(4)**, pp. 357–367, 2000. https://doi.org/10.1177/135676670000600406

[34] Yüksel, I., Developing a multi-criteria decision making model for PESTEL Analysis. *International Journal of Business & Management*, **7(24)**, pp. 52–66, 2012. https://doi.org/10.5539/ijbm.v7n24p52

[35] Dyson, R. G., Strategic development and SWOT analysis at the University of Warwick. *European Journal of Operations Research*, **152(3)**, pp. 631–640, 2004. https://doi.org/10.1016/S0377-2217(03)00062-6

[36] Fernández-González, J. M., Martín-Pascual, J. & Zamorano, M., Biomethane injection into natural gas network vs composting and biogas production for electricity in Spain: An analysis of key decision factors. *Sustainable Cities & Society*, **60**, 102242, 2020. https://doi.org/10.1016/j.scs.2020.102242

[37] Ruá, M. J., Huedo, P., Cabeza, M., Saez, B. & Agost-Felip, R., A model to prioritise sustainable urban regeneration in vulnerable areas using SWOT and CAME methodologies. *Journal of Housing & the Built Environment*, **36(4)**, pp. 1603–1627, 2021. https://doi.org/10.1007/s10901-020-09813-w

[38] ARCH, Recurso, *Agencia de Regulación y Control Hidrocarburífero (ARCH)*, 2017. https://www.controlhidrocarburos.gob.ec/wp-content/uploads/2017/11/Revista-ARCH-2017.pdf. Accessed on: Nov. 26, 2021.

[39] Banapurmath, N. R. & Tewari, P.G., Performance, combustion, and emissions characteristics of a single-cylinder compression ignition engine operated on ethanol—biodiesel blended fuels. *Proc. Inst. Mech. Eng. Part A, Journal of Power & Energy*, **224(4)**, pp. 533–543, 2010. https://doi.org/10.1243/09576509JPE850

[40] Cortez, L. A., Leal, M. R. L. & Nogueira, L. A. H., *Sugarcane Bioenergy for Sustainable Development: Expanding Production in Latin America and Africa*, Routledge: Abingdon, England, 2019.

[41] Albarelli, J. Q., *et al.*, Multi-objective optimization of a sugarcane biorefinery for integrated ethanol and methanol production. *Energy*, **138**, pp. 1281–1290, 2017. https://doi.org/10.1016/j.energy.2015.06.104

[42] Thanarak, P., Supply chain management of agricultural waste for biomass utilization and CO2 emission reduction in the lower northern region of Thailand. *Energy Procedia*, **14**, pp. 843–848, 2012. https://doi.org/10.1016/j.egypro.2011.12.1021

[43] Arshad, M., *Sustainable Ethanol and Climate Change*. Springer Nature: Cham, Switzerland, 2021.

[44] Fernando Iñiguez, J., Reyes, G. G., Rivera, C. A. & Vera, E. S., Estudio De Emisiones Contaminantes Producidas Por Un Motor Otto Con El Uso De Gasolina Y Un Combustible A Base De 95% De Gasolina Y 5% De Etanol. *INNOVA Res. J.*, **2(12)**, pp. 11–18, 2017. https://doi.org/10.33890/innova.v2.n12.2017.571

[45] El Universo, Cañicultores reclaman valores por zafra y etanol, y rechazan importación de biocombustibles, *El Universo*, 2020. https://www.eluniverso.com/noticias/2020/09/29/nota/7995364/protesta-planton-canicultores-etanol-zafra-azucar-mag/. Accessed on: Nov. 15, 2021.

[46] Restrepo-Serna, D., Martínez-Ruano, J. & Cardona-Alzate, C., Energy efficiency of biorefinery schemes using sugarcane bagasse as raw material. *Energies*, **11(12)**, p. 3474, 2018. https://doi.org/10.3390/en11123474

[47] Fazio, S. & Barbanti, L., Energy and economic assessments of bio-energy systems based on annual and perennial crops for temperate and tropical areas. *Renewable Energy*, **69**, pp. 233–241, 2014. https://doi.org/10.1016/j.renene.2014.03.045

[48] Souza, S. P. & Seabra, J. E. A., Environmental benefits of the integrated production of ethanol and biodiesel. *Applied Energy*, **102**, pp. 5–12, 2013. https://doi.org/10.1016/j.apenergy.2012.09.016

[49] El-Faroug, M., Yan, F., Luo, M. & Fiifi Turkson, R., Spark ignition engine combustion, performance and emission products from hydrous ethanol and its blends with gasoline. *Energies*, **9(12)**, p. 984, 2016. https://doi.org/10.3390/en9120984