Review

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Proposal of a regulatory framework for bioenergy implementation in a unified agricultural code for Ecuador

Sebastian Ponce, Department of Chemical Engineering, Institute for Development of Alternative Energies and Materials IDEMA, Universidad San Francisco de Quito USFQ, Quito D.M., Diego de Robles s/n y Av. Interoceánica, Ecuador
Carola Mena-Campoverde, Facultad de Economía, Universidad Católica de Santiago de Guayaquil, Guayaquil, Ecuador
Juan Sebastián Proaño, Department of Chemical Engineering, Institute for Development of Alternative Energies and Materials IDEMA, Universidad San Francisco de Quito USFQ, Quito D.M., Diego de Robles s/n y Av. Interoceánica, Ecuador; Department of Mechanical Engineering, Institute for Development of Alternative Energies and Materials IDEMA, Universidad San Francisco de Quito USFQ, Quito D.M, Diego de Robles s/n y Av. Interoceánica, Ecuador
José Francisco Álvarez-Barreto, Francis Aguirre, Diana Torres Quintana, Juan S. Sanchez Prieto, Department of Chemical Engineering, Institute for Development of Alternative Energies and Materials IDEMA, Universidad San Francisco de Quito USFQ, Quito D.M., Diego de Robles s/n y Av. Interoceánica, Ecuador
Daniela Almeida Streitwieser, Department of Chemical Engineering, Institute for Development of Alternative Energies and Materials IDEMA, Universidad San Francisco de Quito USFQ, Quito D.M., Diego de Robles s/n y Av. Interoceánica, Ecuador; Faculty for Applied Chemistry, Reutlingen University, 72762, Reutlingen, Alteburgstr. 150, Germany

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Abstract: Bioenergy production is a new and promising industry in Ecuador. However, a confusing variety of laws, which are spread among different regulating institutions, regulate the agricultural sector. Such dispersion makes it difficult for farmers and businesses to understand applicable rights, duties, regulations and agricultural policies. Moreover, this rather young industry lacks important experience. In the first section of this work, the existing Ecuadorian legislation on bioenergy is presented and analyzed. Then, a brief, thorough analysis and comparison are carried out for experiences not only in developed countries, but also with similar cultural frameworks and comparable climatic conditions. The results are summarized as specific recommendations that have been handed to the National Agricultural Chamber of Ecuador from academia for the proposal of a Unified Agricultural Code established in the Ecuadorian legal hierarchy as an Organic Law. © 2022 Society of Chemical Industry and John Wiley & Sons, Ltd

Key words: agrobiodiversity; bioenergy; biomass; energy sovereignty; food sovereignty; legislation; sustainability

Correspondence to: Daniela Almeida Streitwieser, Reutlingen University, Faculty for Applied Chemistry, 72762 Reutlingen, Germany. E-mail: d.almeida_streitwieser@reutlingen-university.de

Introduction

Non-renewable fuels supply more than three-quarters of the global energy demand.[1] However, multiple studies suggest that after an immanent peak in extraction of fosil fuels, a dramatic decline in production will influence the future energy supply.[2] Regardless of crude oil depletion, change toward new energy resources is required owing to the pollution caused by the former. Fossil fuel combustion is one of the primary contributors to greenhouse gas emissions, especially carbon dioxide. One of the leading global environmental challenges is mitigating these emissions and stabilizing greenhouse gas concentrations in the atmosphere to mitigate the dangers of climate change.[3] Therefore, energy sustainability must be a priority for all countries, and its evolution is reflected in the development of new technologies that replace non-renewable energy sources.[4] A viable alternative is bioenergy usage, defined as a group of technologies through different conversion routes (see summary in Table 1) that obtain energy from biomass of any origin, including living organisms and their metabolic products, for transport, electricity or heat.[5] Bioenergy sources, generalized as biofuels, can be found in the form of liquids (biodiesel, bioethanol), gases (biogas, synthesis gas) or solids (wood chips, carbon briquettes). Raw material to produce biofuels can be first-generation biomass, such as grains and oilseeds, or second-generation biomass, including agro-industrial, municipal, forestry or other residues.[6]

An example of the Latin American reality is Ecuador, which has been a crude oil exporting country for the last 50 years. The oil market has represented over 20% of the gross domestic product (GDP) over these years, despite a steadily growing Ecuadorian agricultural sector.[7] Among others, sugarcane, African oil palm, hard corn, sorghum, soybeans, sunflower, rapeseed, cotton, *Jatropha curcas*, safflower, peanut, rice husk, banana, cocoa, coffee, heart of palm and pineapple represent ~80% of the national biomass production from a total of 5 448 560 hectares of arable land in 2019,[8–10] with more than 70% of the total production of the country concentrated in 50% of provinces, such as Guayas, Los Ríos, Esmeraldas, Sucumbíos, El Oro, Manabí, Chimborazo, Pichincha, Orellana and Loja.[11] Among them, it is essential to consider the most suitable biomass type for a specific energetic application without affecting the environment or food sovereignty.[12] Table 2 shows a summary of Ecuadorian crops that can be used for biofuel production in dual-purpose or energy crops, and their residual biomass, also considering potential soil damage.

Currently, the country has opted to counteract its economic dependence on fossil fuels with renewable energies, showing good progress in the power sector, where most of the electricity comes from hydroelectric power plants. However, little progress has been achieved in government plans for experimental and pilot-scale projects regarding other renewable energy sources, including those related to bioenergy. In 2020, almost 61% of the electric energy production was obtained from renewable energy sources, with 58% being hydraulic, 0.6% wind and solar and less than 1.7% from biomass or biogas combustion,[13] which is related to the immaturity of biomass conversion technologies in Ecuador, as shown in Table 1. Thus, bioenergy has still a long journey before tackling the Ecuadorian energy problem.

As described above, there are some important obstacles to the effective development and implementation of

Table 1. Main biomass conversion routes for biofuels production as well as global and Ecuadorian status.[69–72]

Conversion route	Product	World status	Ecuadorian status
Fermentation	Biomethane	Commercial	—
	Bioethanol	Commercial	Multiple-scale production for fuel purposes
	Cellulosic ethanol	Demonstration	—
Transesterification	Biodiesel	Commercial	Two private facilities at 'La Fabril'
Anaerobic digestion	Biogas	Commercial	Two combustion units for electricity generation. Combined power ~7 MW
Combustion	—	Commercial	Commercial burners up to 1 MW
Gasification	—	Commercial and demonstration	Multiple small-scale demonstrations
Pyrolysis	Bio-oil	Research, demonstration	Laboratory-scale research
	Biochar	Research, demonstration	Laboratory-scale research
Torrefaction	Torrefied biomass	Research, demonstration	Research and small-scale experimentation
Hydrothermal process	Hydrochar	Research	—
Oxidation	Biogenic formic acid	Research	Laboratory-scale research

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Table 2. Summary of production, potential soil damage, and type of crop for different biomasses in Ecuador.[73]

Main product	Crop type	Derivative	Potential soil damage	Production (10^3 t/year)
Sugar cane	Dual-purpose cultivation	Rachis, bagasse	Degradation	7 379
African palm	Residual biomass	Oil, rachis, kernel	Weakened soils and loss of agricultural capacity	2 649
Hard corn	Dual-purpose cultivation	Grain	Quality degradation	1 215
Rice	Residual biomass	Husk	Erosion	1 565
Banana	Dual purpose cultivation	Leaves, pseudostems, rachis, peels, waste product	Low fertility and degradation	7 012
Cocoa	Residual biomass	Rachis, waste product	Quality degradation	133 323
Coffee	Residual biomass	Shells, mucilage, pulp	Erosion	7 340
Heart of palm	Energy cultivation	Waste product	Erosion	92 500
Pineapple	Residual biomass	Peels, leaves	Loss of soil properties and erosion	100 000

bioenergy technologies. Among others, a lack of long-term contracts between producers and industrializers, a lack of agro-sector evolution data for decision making and long-term planning, a lack of preferential interest rates (credits, subsidies), little protection of small land owners, a lack of a value-chain analysis, a lack of technology and human talent, and vulnerability against external competitors can be mentioned.[14,15]

Additionally, there is an urgent need for a comprehensive agricultural code that encompasses the vast array of policies (laws and codes) in different areas of the agricultural sector (e.g. labor issues, competitiveness, exports, markets, investments, taxes, sustainability) that could enable farmers to know all of their rights, obligations and penalties, particularly with an emphasis on the use of land for bioenergy purposes. Thus, the present work reviews examples of international and regional agricultural and biofuel policies, together with particular Ecuadorian regulations and needs, to assess the importance of developing a Comprehensive Agricultural Policy Framework that promotes the sustainable development of bioenergies in Ecuador. Recommendations from this analysis have been handed to the National Agricultural Chamber of Ecuador.

Diagnostics of the current agricultural legislation framework related to bioenergy development in Ecuador

A brief history

As summarized in Fig. 1, agricultural legislation in Ecuador started with the first Agrarian Reform Law in 1964 with four main objectives: (i) political, to stop communism; (ii) economic, to promote productionl; (iii) social, to improve farmers' conditions; and (iv) justice, to promote land equality. Despite good intentions, the Law was flawed. Then, a second reform was subscribed in 1973, in which a capitalist system was introduced to the sector, with high State support, especially for exportable products, and subsidies for agro-chemicals and machinery. This period, known as the first oil bonanza, generated resources to invest in the agricultural sector. The aim was to move from large farms to smaller production units accessible to smaller farmers. As a result, greater technification and lower production costs propelled the development of agriculture. In general, the policies were limited to a project of agrarian regionalization, agricultural marketing, access to credit, irrigation, agricultural research and importation of technology.[16–18]

Later, in 1979, the Agricultural Development and Promotion Law was issued to strengthen the business perspective of medium and large farm owners. In the 1980s, with falling oil prices, subsidies and support for the sector were undermined, and incentives to the export sector of agricultural products were intensified. Basically, policies were directed or limited to price policies, exchange rate management, tariff system reform, support for farmers of exportable products, and reduction or elimination of subsidies.[16]

A few years later, in 1994, the Agrarian Development Law was established, which sought to comply with policies for improving the functioning of product and factor markets in rural areas, promoting the development of institutions to meet the requirements of the expanding rural economy, and creating the appropriate legal framework for agricultural development. In 1997, a boost was given to exports to

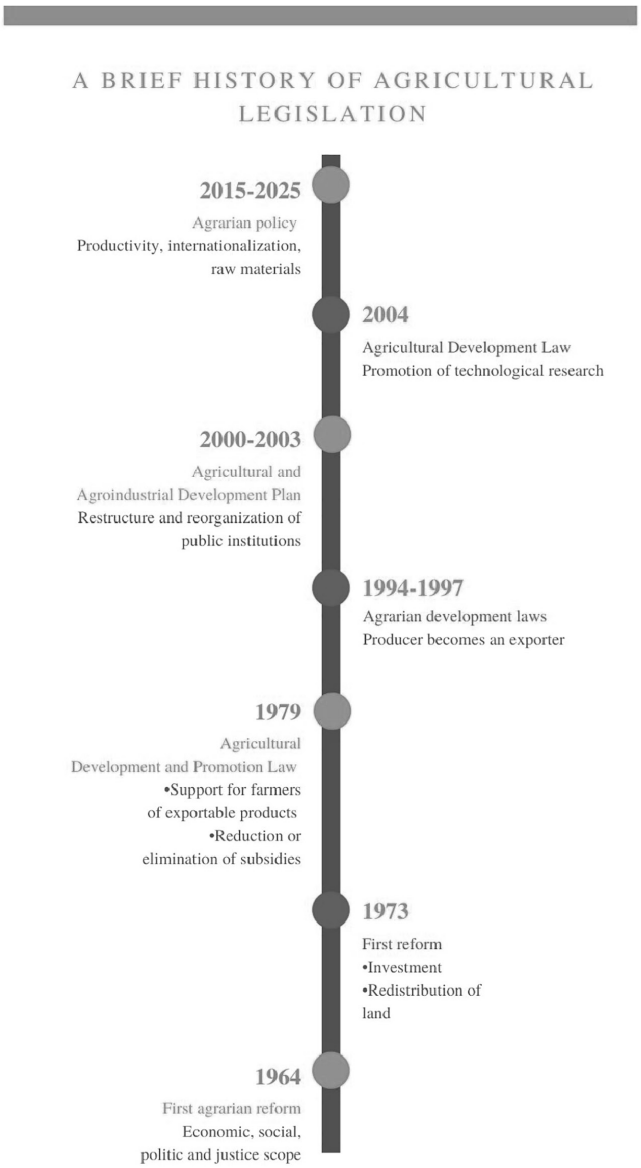

Figure 1. A brief history of Ecuadorian agricultural legislation.[16–18]

avoid intermediaries and transform the farmers into direct exporters.[19]

Regarding the agricultural legal evolution for the twenty-first century, the Agricultural and Agroindustrial Development Plan, 2000–2003, was launched. The Agricultural Sector Program was created, seeking the liberalization of Agricultural Production and Input Markets through reform of pricing and foreign trade policies, modification of land and water policies, restructuring of agricultural companies and institutions of the Agricultural Public Sector, reorganization of the Ministry of Agriculture and reformulation of Public Expenditure in the sector. This was then followed by the Agricultural Development Law (2004), which comprised several important policies (promotion of scientific and technological research, stimuli of investments, free import, credit insurance, indigenous training, and others).[20]

Recently, in a public policies report by the Ministry of Agriculture and Livestock (2016) for the period 2015–2025, the agricultural policies aimed to solve problems of low productivity, high dependency on raw materials, inputs and capital goods, high levels of means of production and insufficient promotion of diversified productive activities that generate decent working conditions in all spheres. Moreover, this legislation seeks to empower human talent with low specialization and a low level of training and education, combine strategic sectors for diversifying the productive matrix, and decrease unfavorable conditions in the productive sectors, like access to credit. It also tackles strategies to identify and access national and international markets, as well as weaknesses in research and development activities in the sector.

Furthermore, in 2020, policies for agricultural management in Ecuador were added[21] in relation to the promotion of productivity and quality, the guidance and development of markets, access to services and infrastructure, strengthening of partnership and participation, environmental sustainability and adaptation to climate change and modernization, and institutional and legal innovation.

Despite a clear development of the agricultural sector during recent decades, there is still no unified legal framework regulating and guiding bioenergy development in the country. However, it has been recognized that its proper development in Ecuador will provide opportunities in the economic sector by increasing agricultural production, boosting the rural workforce and promoting efficient systems.[4] The following section summarizes and analyzes the current legal framework for the development of bioenergy in Ecuador.

Compilation of current Ecuadorian legal information

As a first step, an understanding of the current Ecuadorian legal system is necessary for the analysis. Subsequently, legal norms regarding the country's energy development, specifically related to bioenergy, renewable and clean energies, and agriculture (such as land use, food sovereignty and development), were thoroughly analyzed for specific regulations in the topics of interest. In Fig. 2, the country's hierarchy of laws is presented through a Kelsian pyramid.

As shown in Fig. 2, Ecuador is currently ruled by the 2008 Constitution, followed by lower hierarchical documents

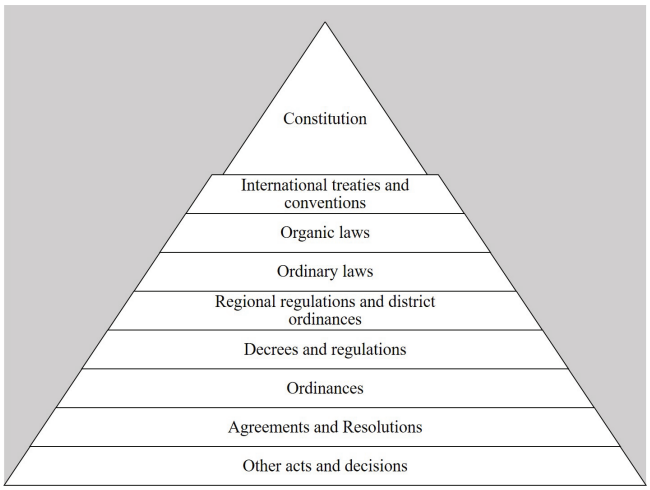

Figure 2. Legal hierarchy of Ecuador, according to Article 425 of the constitution.[22]

like international treaties, laws, regulations, ordinances, etc. Related to this study, Ecuador's Constitution confirms the commitment to promote investment in the public and private sectors and implement environmentally clean technologies and non-polluting low-impact alternative energies. On the latter, the importance of achieving energy sovereignty without affecting essential goods for the population, such as food sovereignty and water rights, is emphasized for ensuring the population's good living via production processes that satisfy internal demand. Following the global objective of reducing greenhouse gas emissions to improve environmental quality, the Constitution of Ecuador also mentions its determination to promote energy efficiency and the development and use of environmentally clean practices and technologies, along with renewable, diversified and low-impact energy.

Table 3 lists the existing legal documents and their respective Articles, contemplating the five key topics related to bioenergy development and implementation. It is noticeable that sustainability is the most widely covered topic in Ecuadorian Laws (78 Articles), while agrobiodiversity, energy sovereignty and food sovereignty are less mentioned. In the following subsections, a summary of the topics is presented.

Governmental position and the National Development Plan

The Constitution contemplates in Article 280 the creation of development plans. The 'National Plan for Good Living' (PNBV, in Spanish) is proposed as the framework to which public policies, programs and projects will be subjected, in addition to economic aspects, such as the programming and execution of the State budget. Likewise, this plan defines the investment and allocation of public resources and responsibilities of central State and Local Governments (Decentralized Autonomous Governments, or GADs in Spanish).[22]

GADs are decentralized institutions that enjoy political, administrative and financial autonomy; therefore, they play a key role in the development of bioenergy and promotion of agricultural production associations. Accordingly, the Organic Autonomous Decentralized Territorial Code designates competences to the GADs at Regional (e.g. policies for research and innovation knowledge and technology transfer), Provincial (environmental management, promotion of agricultural activity), Cantonal (land use control, basic services), and Parochial (investment and development of agriculture, livestock) levels.[22]

Ecuador began its initiative to shift the energy matrix into renewable sources in 2009, and since then, two development plans have been proposed:

1. The PNBV 2009–2017 consists of two manuscripts written between 2009 and 2017. Regarding energy, three objectives outline the intended reform of the country's energy sector: (i) to promote efficiency and the greater participation of sustainable renewable energies as a measure to prevent environmental pollution; (ii) to ensure sovereignty and efficiency of the strategic sectors for industrial and technological transformation; and (iii) to restructure the energy matrix under criteria of transformation of the productive matrix, inclusion, quality, energy sovereignty and sustainability.[23]
2. The 'National Development Plan 2017-2021' (PND 2017–2021 in Spanish) has recently been established. It seeks to adopt the necessary measures to achieve 'Good Living'. Thus, great importance is given to restructuring the economy by reducing dependence on fossil fuels, orienting the change to an economy based on biodiversity. Its objective is to establish a new era of bioeconomy based on the sustainable use of renewable organic resources to produce energy, through the transformation of biomass.[24] Based on this philosophy, environmental policy is established as part of the collective effort to build an environmentally responsible country.

Food sovereignty

The previously mentioned policies could enhance development of the agricultural infrastructure for bioenergy development, but they could also be threats to food sovereignty, a global priority. These threats should be tackled by respecting cultural diversity, starting from the agricultural

Table 3. Summary of legislation containing topics related to bioenergy development and implementation.

Legal document	Articles within the legal document related to each topic				
	Government position	Food sovereignty	Energy sovereignty	Sustainability	Agro-biodiversity
Constitution of the Republic of Ecuador	285; 319; 320; 414	133; 281; 400	15; 261; 413	282; 409–410	401
Organic Law of Rural Lands Ancestral Territories	—	19	—	4; 6–7; 12; 29; 31; 45–47; 49; 53; 88; 110	—
Regulation to the Organic Law of Rural Lands Ancestral Territories	—	7	—	—	—
Organic Law of Water Resources Uses and Use of Water	—	93	—	3; 93–95; 98–104; 107; 113	—
Regulation of the Organic Law on Water Resources Uses and Use of Water	—	83; 85	—	2; 82–83; 85–87; 89	—
Environmental Regulation of Hydrocarbon Activities	67	—	—	—	—
Organic Law on Agrobiodiversity, Seeds and the Promotion of Agriculture	—	1; 8	—	—	8; 27–37; 48–52; 56
Organic Law of the Food Sovereignty Regime	—	1; 3; 7; 8	—	—	8
Organic Law of Agricultural Health	—	—	—	—	21; 51
Organic Law on Energy Efficiency	—	—	1; 3; 20	—	—
Environmental Regulation of Hydrocarbon Operations in Ecuador	—	—	57	—	—
Agricultural Oil Authorization Regulation Spray Oil	—	—	1; 4	—	1; 4
Organic Law of the Public Electricity Service	1–2; 11; 13; 26	—	1–3; 11; 13; 26	—	—
Organic Code of the Environment	—	—	—	9; 211; 213; 219–220; 225; 228; 231; 239; 243; 245; 288–297; 314–332	—
Investment and Productive Development Code	4; 98; 234	5; 57; 59; 61	5; 59	232; Ref, 9,1.	—
Productive Promotion Law	—	35	35	—	—
Total number of articles	13	19	18	78	24
Number of documents	4	9	7	6	5

sector to manage rural areas. This strategy is supported by the United Nations Sustainable Development Goals 2 (Zero hunger) and 12 (Responsible consumption and production, promoting an increased resource efficiency and a sustainable lifestyle).[25]

In the Ecuadorian context, food sovereignty is defined as 'a strategic objective and an obligation of the State in order to ensure that communities achieve self-sufficiency with respect to healthy and culturally appropriate food on a permanent basis' (Article 281).[22] The State is responsible for guaranteeing access to food, regardless of nationality, in a self-sufficient, permanent, healthy and culturally appropriate way. In order to achieve this objective, the country assumes responsibility for promoting redistributive policies that allow access to land, water and other productive resources to farmers.[22]

Precisely, to protect food sovereignty, the Organic Law of the Food Sovereignty Regime seeks to establish mechanisms through which the State complies with its obligation and the strategic objective of guaranteeing the self-sufficiency of healthy, nutritious and appropriate food permanently to people and communities (Article 1[26]). This Law establishes the parameters allowed to allocate resources that could be used to produce food, alternative materials like biofuels, or bioenergy in general. Article 3 of this Law encourages the consumption

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of agroecological and organic healthy and nutritious foods, avoiding, as much as possible, the expansion of monocultures and energetic crops for the production of biofuels.

According to the legislation, GADs should provide the necessary infrastructure for direct exchange and commercialization between small producers and consumers as a new relationship for mutual benefit in a Social and Solidarity Economy. This Law establishes the mechanisms for price regulation to protect micro, small and medium-sized producers as well as consumers, who will participate equally, avoiding and sanctioning unfair, monopolistic, oligopolistic and speculative competition.[23]

In this context, Ecuadorian law promotes and ensures agricultural sustainability, always prioritizing food crops over energy crops. The tools available are credits at preferential rates, associativity, price regulation, centralized warehouses, investment support, technology, research, training, subsidies, weather-related insurance and market-related insurance.

Energy sovereignty

In Ecuador, various projects have been implemented to innovate and guarantee its energy supply, as stipulated by the Constitution. In Article 15, environmentally clean, non-polluting, low-impact technologies are promoted for the public and private sectors. This Article highlights that 'energy sovereignty shall not be achieved to the detriment of food sovereignty nor shall it affect the right to water'. In general, Article 413 in the Constitution promotes the development of technologies seeking energy efficiency.[22]

Based on this responsibility, the Organic Law on Energy Efficiency was created. Its main objective was to promote the efficient, rational, and sustainable use of energy in all forms to improve energy security (Article 1[27]). This Law raises the need to improve productivity and competitiveness through cost reduction and efficient energy management, thus favoring scientific research, technological development and the participation of national companies. The Secretary of Higher Education, Science and Technology and Innovation acts as the coordinator of these research activities that the Ecuadorian State may finance (Articles 3 and 20[27]).

The goal of the State is to build an economically and ecologically balanced electricity matrix, increasing the participation of clean and renewable energy resources,[24] as stated in Article 1 of the Organic Law of the Public Electricity Service. These renewable energies come from sources that do not diminish with their use, such as wind energy, biomass, biogas, photovoltaic, geothermal and hydroelectric (Article 3[28]). In this Law, it is also mentioned that the State will prioritize the support of biomass for energy purposes if it originates from solid waste (Article 2[28]). Electricity sector planning, renewable energies and energy efficiency are regulated by the Ministry of Electricity and Renewable Energy, as established in this same Law (Article 13[28]).

Sustainability

Sustainability refers to the joint development between human actions based on their environment and, above all, how this relationship can generate conservation of the diversity and productivity of biological systems. Therefore, a nation must seek through its policies a long-lasting balance between economy, society, ecology and politics.[29] Three important aspects are considered to promote bioenergy based on agricultural resources in Ecuador: land use, the use of water and the different environmental policies applied.

Use and access to land are considered important strategic instruments for the country's sustainable economic and social development.[30] Article 282 of the Constitution appoints the State as the competent authority responsible for the social and environmental regulation of land use and access, emphasizing farmers' rights and fair access to national land.[22] Moreover, Articles 409 and 410 establish that maintaining the fertile soil layer is a national priority.[31] Article 7 in the Land Law promotes the efficient use of soil to maintain proper management and provide social, economic and environmental development to ensure the well-being of the population. Article 12 of the Land Law establishes the conditions to promote sustainability of renewable natural resources and agrobiodiversity in agricultural activities.[31]

The National Agrarian Authority is the entity responsible for coordinating and regulating public policies to use rural lands based on agricultural activities that guarantee food sovereignty (Article 31[31]). The agricultural development zones and the plans to regulate the correct use of soils for productive activities are established between the National Agrarian Authority, the State and the GADs of each province (Article 45[31]).

The water resources are regulated in Ecuador through the Organic Law of Water Resources, Uses and Exploitation of Water, whose objective is to guarantee the rightful use of water for the people and nature (Article 3[32]). The use of water for productive activities, such as those required for agricultural development, is a priority since it guarantees food sovereignty. However, according to Article 318 of the Constitution, water resources can also be used for human consumption, ecological flow and other productive activities (Article 318[22]). Regarding productive activities, this refers to the use of water for activities not considered in food sovereignty in terms of agricultural or aquaculture production (Article 93[32]). The Secretary of Water regulates, gives licenses and controls water resources for industrial productive activities (Article 2[33]). According to Article 95

of the Law on Water Resources, water can only be provided for productive activities if water resources are available in sufficient quantity and quality. In addition, the industries are responsible for preventing and mitigating environmental hazards caused to water resources during the production processes.[34] The authorizations provided for productive activities that are not part of the food sovereignty policy have a validity of up to ten years (Article 85[33]).

Moreover, all industrial activities need to be aware of the impact they generate on the environment. In Ecuador, clean energy is promoted by recognizing the importance of incorporating better environmental practices by the sustainable production and consumption of goods and services to reduce pollution and optimize natural resources (Article 9[35]). In Article 243 of the Organic Code of the Environment, the National Environmental Authority is established as the responsible entity to promote new systems for producing and consuming environmentally sustainable goods to guarantee human life quality and reduce the ecological footprint. The proper management of waste and residues is also promoted and regulated by the National Environmental Authority, which goes hand in hand with clean and sustainable production mechanisms (Article 245[35]).

The National Environmental Authority also regulates the utilization of chemicals in agricultural production to improve and guarantee crop growth (Article 211[35]). The most common substances used for this purpose are fertilizers and pesticides. However, their inappropriate utilization can cause the opposite effect, contaminating water resources by eutrophication, denaturing soils and causing health problems in vulnerable populations or affecting animals or plants.[36] Finally, the National Environmental Authority is also responsible for keeping dangerous chemical substances out of contact with food, medicine, clothing and any other objects, and for the correct final disposal of the waste that they may generate (Article 211–223[35]).

Agrodiversity

As mentioned above, the concept of agro-energy refers to the use of biomass for energy purposes. This biomass comes from capturing and transforming solar energy, allowing land usage to solve energy problems sustainably. The commonly used biofuels in Ecuador are bioethanol and biodiesel,[37] obtained from sugar cane and palm oil, respectively.[38] These crops also need to meet the requirements for sustainable agriculture, defined in Article 48 of the Organic Law of Agrobiodiversity, Seeds, and Promotion of Agriculture, hereinafter called the Law of Agrobiodiversity. Sustainable agriculture seeks ways to produce food in a stable, healthy, economically viable and socially acceptable way, maintaining a balance with the environment.[39]

For this reason, palm oil production has to comply with the Regulation for the Authorization of Agricultural Spray Oil, where the provisions and procedures necessary to obtain authorization to produce, import and market it under the name of agricultural oil or 'Spray Oil' are established. Article 4 of this Law establishes that the executive director of the Agency for the Regulation and Control of Hydrocarbons may grant these authorizations.[40] However, there is still no regulation for bioethanol production.

Seeds play a vital role in the performance of the agricultural sector.[41] For this reason, in Article 401 of the Constitution, Ecuador is declared as a zone free of transgenic crops and seeds.[22] Also, the Law of Agrobiodiversity establishes the right to free production, conservation, commercialization, exchange and access to all kinds of seeds: native, traditional and certified (Article 8[39]). For Ecuador, it is essential to maintain the native seed as a heritage (Article 27[39]).

In summary, the Ecuadorian Constitution and existing Organic and Ordinary Laws already include the basic criteria to develop sustainable agriculture for bioenergy production; however, these laws are dispersed in different documents, as shown in Table 2, and the practical application of the regulations is complicated. This dispersion makes it difficult to find correct connections between the five key topics, mentioned above, which should work in parallel, as equally important. For achieving the Paris Agreement, for instance, Ecuador should go through a deep decabornization process with the incorporation of bioenergy into the energy matrix. Around 500 000 ha of land would be required for bioenergy feedstocks.[42] Thus, the omission of some of the key topics, at the moment of bioenergy implementation, can cause irreparable problems in the future.

Moreover, there is no legislation or policy that specifically clarifies guidelines for biofuel development. As a result, most initiatives concerning bioenergy expansion are carried out by governmental policy rather than by law. Therefore, organizing the legal framework to obtain a single document with practical application and specific guidelines will take time and needs multidisciplinary highly educated specialists to do so.

The following section shortly summarizes international experiences related to bioenergy development that can help to define specific guidelines for an improved Ecuadorian regulatory framework.

Relevant international experiences in bioenergy

A crucial way to address the environmental problems implicit in the use of fossil, non-renewable energies to produce heat, electricity and fuels for transportation is

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to change the energy sources.[43] The accelerated growth in the production and use of bioenergy in recent years is generating interest from investors worldwide. Global biofuel production has had a 7% year-to-year growth in the last decade[44] (see Figure 3, black columns for the global biodiesel production growth in the last decade). World leaders are continuously searching for new renewable and sustainable resources to produce the energy required to fulfill the needs of current and future societies, while governments are implementing new legal frameworks to boost the shift into a sustainable development.

This diversity has driven many countries, such as the USA, China, Spain, India and Germany, to rely on bioenergy development.[45] Therefore, they could work as interesting examples for the experiences and regulations needed in the Ecuadorian energy sector. However, it is also relevant to analyze countries with similar geographical, agricultural and cultural characteristics to the Ecuadorian reality in terms of the same energy crops and other biomass sources and regulatory approaches. Some of the countries that have enacted new pro-biofuel policies include Brazil, Argentina, Australia, Canada, China, Colombia, India, Indonesia, Malawi, Malaysia, Mexico, Mozambique, The Philippines, Senegal, South Africa, Thailand and Zambia, among others.[46,47] Figure 3 shows the biodiesel production trend for some of the countries listed above. Most of them display a steady production growth in the last decade, in contrast to Ecuadorian manufacturing, which is limited to small pilot plant projects and scarce commercial production. However, bioenergy implementation would represent technological implementation and better use of resources. For instance, it is known that a 5% mix of biodiesel into diesel would demand 140 000 t of palm oil, growing a well-developed Ecuadorian industry. On the other hand, a bioethanol (10%)–gasoline (90%) mixture at the national level would create around 130 000 jobs and savings close to 700 million dollars. Thus, international exemplary development is for sure relevant to the Ecuadorian reality.[48,49]

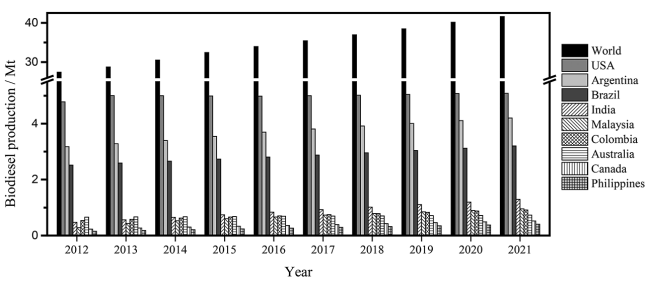

Figure 3. Global and country examples for the production of biodiesel.[74]

Short summary of policies and regulations for promoting bioenergy production and use

The motivations and policies for bioenergy production and usage have evolved continuously in different countries. For example, Argentina has been motivated since the 1970s to produce biofuels, but it was only after 2006 that the Government founded the legal basis to start the production of bioenergy with Laws 26.093 and 26.334, which regulate and promote the production and sustainable use of biofuels, specifically bioethanol.[50] Argentina, for instance, has a set of federal laws that provide an environmental regulatory framework, such as the National Environmental Policy, Environmental Protection of Native Forests, and Industrial and Service Activities Waste Management. Additionally, as a federal constitution, each province may issue its specific regulations. Some of the environmental measures taken in Argentina include environmental damage insurance for projects or activities capable of producing biomass. Regulatory enforcement also increases control over actions that could produce environmental damage.[51]

On the other hand, the Brazilian Government as early as 1903 proposed infrastructure for the production and use of bioethanol for automobiles to reduce fuel imports.[52] In Brazil, Law 9.427/1996 authorizes the National Electric Energy Agency to implement rates and discounts, depending on the source of electric energy.[53] This Law rewards the use of renewable energy sources, such as solar, wind, biomass and others qualified as 'environmentally friendly', with lower prices or discounts. Also, Law No. 9.478/1997, which regulates the utilization of energy sources to preserve national interest, promotes bioenergy development while protecting the environment and the conservation of energy.[54] Additionally, Resolution No. 514 from the Ministry of Mines and Energy opens up a free market in the energy sector until 2028, implying that power producers and traders can freely negotiate energy prices.[53] Lately, in 2019, the Brazilian Supreme Court enacted a regulation of land use and forestry protection with the New Forest Code. There are measures involving the Rural Environmental Registry, which focuses on land use management on Legal Reserve and Permanent Preservation Areas. Like Argentina, there is environmental insurance in Brazil to protect soil quality and control contaminated areas.

The USA is one of the countries with vast investment of economic resources in the study and prospects of bioenergy. The Environmental Protection Agency oversees many clean energy programs, creating networks between the public and private sectors.[55] Moreover, the Energy Policy Act of

2005 establishes well-defined objectives and regulations. For instance, all motor petrol sold had to have a minimum renewable fuel content of 7.5 billion gallons by 2012. Moreover, around 500 million dollars were invested for promoting the use of biotechnology for obtaining biofuels from cellulosic feedstocks, among other funding incentives.[56] Interestingly, the Low Carbon Fuel Standard regulates the carbon intensity of transportation fuels, establishing an average carbon intensity value (e.g. in g CO_2e per MJ of fuel), using market mechanisms to do so in a cost-effective manner. Nevertheless, its real application faces many obstacles owing to economic impacts.[57]

In Asia, many countries have adopted the use of bioenergy, such as Indonesia, which actively pursues the development of an alternative energy industry after global fuel prices soared in 2004. First, the Indonesian Government reduced and then dropped the fuel price subsidies in 2005 to allow the biofuel industry to be economically viable.[58] To ensure a secure domestic energy supply and encourage sustainable development, Presidential Regulation 5/2006 was passed. The main goal was to lower dependence on oil, gas and coal while increasing biofuel, geothermal and other renewable energies. Law 30/2009 allows the State to control the energy sector, ensuring its availability in adequate quantity and quality, at reasonable prices, considering sustainable development.[59]

Environmental protection is mainly regulated by Law 32/2009. Additionally, Law 23/2014 gives regional autonomy for implementing other regulations different from the National Environmental Law. However, all of them focus on the prevention and control of forest and land fires. Regarding land, to prevent adverse impacts, compensation should be paid in the case of water or soil contamination, and particular actions must be taken if there is any soil or groundwater contamination.[60]

The Philippines started encouraging bioenergy in 2007. Act 9367 describes the use of alternative transport fuels to reduce dependence on imported fuels.[46] In the Philippines, some major laws protect the environment. For example, the Republic Act 9275 protects water bodies from industrial and commercial, agricultural and residential pollution.[61] Another regulation is the Presidential Decree 1586 to facilitate the balance between socio-economic development and environmental protection. The latter addresses environmental risks through planning and management.

In Africa, despite the lack of a proper policy framework, several efforts to encourage the use of biomass resources have risen. A clear example is Kenya, which has promoted initiatives to pursue and facilitate the production of biofuels with tax incentives; however, there is still much to do to develop a national strategy that helps the sustainable growth of bioenergy. Impacts of the potential conflicts in land use between production for bioenergy and meeting food demands are already gaining importance. Land use impact is greatly dependent on crops. However, in some countries, particularly those in Africa, there is growing concern that there might not be enough land to produce enough biomass for food consumption and replace or blend fossil fuels.[62] Thus, large-scale bioenergy implementation must include regulations to protect cropland for food production.[63] In Africa, it is projected that the continuous use of land for *Jatropha curcas* monoculture will have detrimental impacts on the regional hydrological cycle.[64] To avoid soil damage and excessive environmental impact, *Jatropha* should be cultivated on low-carbon stock land with added arbuscular mycorrhizal fungi.[65]

Inadequate agricultural practices have also generated important impacts on water resources. Kenya showed that 1000–2000 liters of water are required to process one ton of sugar into ethanol. Also, the foul smell and dark color of the wastewater from ethanol production is a potential cause of conflicts with local communities.[62] Dedicated biofuel crop production impacts on water quantity and quality are more significant than those from processing it. The water footprint of biomass tends to be 70–400 times larger than that of other primary energy carriers like crude oil or other renewable resources, excluding hydropower energy.[66]

Conclusions

Similar to the African situation, in Ecuador there might not be enough land to produce enough food for consumption, owing to its replacement with energy crops. According to Martí et al.,[67] based on a territorial organization model, assigning 34% of the arable land to energy crops and 66% to food crops, a 25% substitution of the national production of fossil fuels with biofuels could be achieved, optimizing gross domestic product (GDP). However, as far as the authors know, there is no territorial planning to define the lands suitable for energy and food crops without affecting food sovereignty in Ecuador, showing a clear misalignment between existing regulations and proper planning, execution and real application of them. Thus, adequate planning to define the relation between food and energy crops is required. Studies like Martí et al.[67] could serve as the basis for determining energy crop planning, but close and direct communication between the Ministry of Renewable Energies and the Ministry of Agriculture is necessary.

Nonetheless, and despite being an oil-exporting country, Ecuador imports large amounts of liquid fuels to provide the transportation sector with the fuels demanded, spending a considerable amount of money in subsidies, paying about

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US$0.33 and 0.90 per gallon of extra gasoline and diesel 2, respectively.[68] Thus, following the Indonesian example, dropping the fuel price subsidies would make biofuel industry more viable in Ecuador.

Even though the Ecuadorian government has implemented a plan for the production of bioetanol called 'Ecopais', with the creation of around 55,000 direct and indirect jobs at the artisanal level,[49] the application of blended fuel with renewables is still rare at industrial scale. In this sense, some mechanisms for the real implementation of existent laws are absent. Ecuador could learn from international experiences to complement its present regulatory framework by adding regulations that really drive investment, incentives, discounts and lower prices for minimizing risks for farmers and providers.

Comparing different international and Ecuadorian laws that drive environmental sustainability, it is confirmed that Ecuador has a good framework of legal protection for the environment and strict sanctions. Municipalities, as in other countries, are responsible for applying the laws and promoting environmental policies for adopting new projects and enforcing the regulations. However, the bioenergy industry is still young, and thus environmental impacts are not as visible as in other latitudes. As mentioned several times in this document, the compilation of laws in one document could help ease application of the well-elaborated existing laws. Below, are listed some recommendations developed from academia and handed to the National Agricultural Chamber of Ecuador.

Recommendations

Within the bioenergy industry, farmers are the providers of the raw material, and industries are responsible for the transformation of the biomass into valuable energy sources. The Ecuadorian Constitution and existing Organic and Ordinary Laws already include the basic criteria for the development of sustainable agriculture for bioenergy production. However, these laws are dispersed in different documents, and the practical application of the regulations is complicated (see Table 3). As a result, bioenergy implementation in Ecuador is still scarce. Therefore, the preparation of a comprehensive regulatory framework, capable of establishing promotion strategies, protection mechanisms, responsibilities and limitations for the agricultural activities and its industrial transformation, in one document is recommended. The proposal of a Unified Agricultural Code established in the Ecuadorian legal hierarchy as an Organic Law has been sponsored by the National Agricultural Chamber of Ecuador with the participation of different actors involved in the supply chain for bioenergy production. Here, the specific recommendations from academia concerning bioenergy development are presented in the following points:

1. Create a national-level entity to oversee the productive development of bioenergies. The main role of this new entity will be coordinating efforts between the Ministry of Renewable Energy, the Ministry of Agriculture, the Ministry of Hydrocarbons, GADs, farmers' associations, biomass transformers and the end customer. This committee, together with experienced international consultants (e.g. from Argentina, Brazil, Colombia), should promote the development and protection of bioenergies and could outline the specific policies of the sector on regulatory frameworks, technical standards, tax incentives, preferential credits, land use and planning, insurance, market regulation (internal, external prices), contractual relationships with transformers, technology training, associative models, promotion to joint projects for biorefineries, focalized subsidies, environmental impacts, assurance of Food Sovereignty and fair markets.
2. Based on international policies, defining conversion routes and/or technologies will guide the transformers and help focus the incentives. For example, anaerobic digestion, sugar fermentation and fat transesterification are established technologies (close to the current global status) for producing biofuels (e.g. biogas, bioethanol, biodiesel). Other technologies, i.e. thermochemical methods, are well studied, but large-scale applications are still limited to academia.
3. Based on common features of international policies, the Government should endorse plans and projects with special incentives for investment support, credits, tax benefits and credit payment terms, to ensure long-term stability to energy-related endeavors.
4. Define clear and affordable objectives for the upcoming years, for example, blended gasoline formulations (biofuel percent content), power and heat generation (installed capacity), international investment, crops surface areas, type of crops (see recommendation 5), research funding (as a percentage of GDP), technological investment (as a percentage of GDP), subsidies, monetary penalties, reduction of carbon emissions, etc. (The Energy Policy Act of 2005 and the Low Carbon Fuel Standard policies are good examples.)
5. Define the energy crops that the Government will promote. For example, sugar cane, palm oil, corn and pine nuts, as the most relevant without neglecting cocoa, bananas, and beets with proper control of potential dangers to the soil and water consumption, as shown in the African scenario. Additionally, promote the use of residual biomass from food production for transformation into biofuels through targeted incentives.

6. Develop a proper territorial organization model, via academia and government, for a clear definition of areas destined for the cultivatation of energy and food crops, avoiding endangering food cultivation. Also, define protection initiatives for small landowners.
7. Define a national system for monitoring present and future prices and markets for biofuels.
8. Promote the triple helix of innovation, between government, university and industry for finding new routes of bioenergy production and application, e.g. oxidation, thermochemical and fermentation processes still require basic research before industrial application.
9. Government and academia should promote the education and integration of human talent for the whole bioenergy and biofuels supply chain related to laws, technology, conversion routes, agricultural management, etc.
10. Regulate and monitor contractual conditions for payment transactions between biomass producers and transformers, to avoid working capital problems, owing to the delayed payments of up to 6–8 months regularly reported nowadays. Banking mechanisms such as factoring can be used, but above all, give preferential credits to biomass transformers to promptly pay farmers.

In a future contribution, with the gaps identified in this revision, more technical recommendations will be produced to promote and extend the production of energy, fuels and chemicals.

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Sebastian Ponce

Sebastian Ponce is a lecturer and researcher at the Chemical Engineering Department at Universidad San Francisco de Quito (USFQ). He holds a PhD from the Technical University of Darmstadt (Germany). His research focus is on reaction engineering related to biomass valorization, chemical recycling, and the synthesis of advance materials for catalysis.

Carola Mena Campoverde

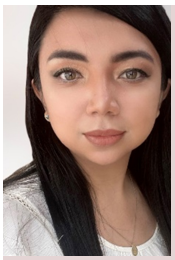
Carola Mena Campoverde is a lecturer at the Universidad Católica de Santiago de Guayaquil and Pacific University (Ecuador) in subjects such as Financial Engineering, Corporate Finance and Economic Engineering. She holds a Master's from the 'Universidad Autónoma de Barcelona' (Spain), and is currently finishing a Doctoral Program at the 'Universidad Nacional de Rosario' (Argentina).

Juan Proano-Aviles

Juan Proano-Aviles is a mechanical engineering professor and researcher at USFQ. He holds a PhD and a MEng from Iowa State University. His research interests include biomass transformation into fuels and chemicals, simulations of engineering processes using CFD and biochar applications.

Jose F. Alvarez

Jose F. Alvarez is Professor and Chairman at the Department of Chemical Engineering at USFQ, and Principal Investigator of the Biomaterials Laboratory. His special focus is on polysaccharide-based biomaterials for applications in tissue engineering and controlled drug delivery with an interest in starches, pectins, chitosans and other biopolymers obtained from agricultural wastes.



Francis Aguirre

Francis Aguirre is currently and administrator of the 'San Francisco' farm, where she is in charge of improving the production and productivity of the agricultural area, crop diversification, efficient use of new irrigation technology, pest and disease control, and management of harvest and post-harvest processes. She holds an engineering degree in Agribusiness from USFQ.

Diana Torres-Quintana

Diana Torres-Quintana is a D&M Field Engineer Trainee at Schlumberger. She holds a Chemical Engineering degree from USFQ. She is dedicated and motivated in the field of process engineering, with experience in troubleshooting and managing daily functions within a laboratory, an industrial plant or an office.

Juan Sanchez-Prieto Jr

Juan Sanchez-Prieto Jr is a process engineer at John Wood Group PLC. He holds a Chemical Engineering degree from USFQ. He is motivated to work in important sustainable process fields with a vast knowledge in process engineering software.

Daniela Almeida-Streitwieser

Daniela Almeida-Streitwieser is a professor in the Master of Environmental Sciences at the Faculty Applied Chemistry at Reutlingen University, Germany. Her expertise lies in the development of new technologies for the utilization of biomass and residues as alternative energy sources and alternative materials with value added to their components.