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The importance of chemical engineering in the Academy-Industry-Government-Society Alliance (AIGS) in the Colombian Caribbean region

Importancia de la ingeniería química en la alianza Academia-Industria-Gobierno-Sociedad (AIGS) en la región Caribe colombiana

Edison Albert Zuluaga-Hernández*
Arley Alexander Reales Ruiz**
Natalia Terán Acuña***

* Professor, Facultad de Ingenierías Universidad de San Buenaventura-Cartagena (USB). Ph.D. in Engineering. Research professor in simulation of physicochemical processes focused on the detection of greenhouse gases. Orcid ID: https://orcid.org/0000-0001-8994-7652. edison.zuluaga@usbctg.edu.co.

** Research Assistant, Facultad de Ingenierías Universidad de San Buenaventura-Cartagena (USB). Chemical Engineer. Focused on carrying out experimental activities and developing research projects. Orcid ID: https://orcid.org/0009-0008-9048-3259. aarealesr@miusbctg.edu.co.

*** Professor, Facultad de Ingenierías Universidad de San Buenaventura-Cartagena (USB). MSc. in Material Engineering. Professor and director of the chemical engineering program. With extensive experience in processes for managing qualified records and accreditation of academic programs. Orcid ID: https://orcid.org/0000-0002-0556-5866. natalia.teran@usbctg.edu.co.

Correspondencia: Edison Zuluaga-Hernández. Cartagena. Carrera 81 nº. 31E-30.

Abstract

Chemical engineering is crucial in society and can contribute to the collaboration between Academy, Industry, Government, and Society (AIGS) to promote sustainable projects and knowledge transfer in the Caribbean region of Colombia. This study examines the impact of chemical engineering in the region, including program offerings, indicators of chemical engineering programs, job market, and opportunities for projects with societal impact. Four public and private institutions have been identified, each offering comprehensive 10-semester study programs designed to cultivate both technical expertise and humanistic education in aspiring chemical engineers. These programs aim to equip students with the necessary tools to tackle the pressing challenges of sustainability. The curriculum is structured into distinct components: foundation (34 %), engineering basics (17 %), professional (39 %), and humanities (11 %). However, disparities in student enrollment numbers between public and private institutions have emerged, posing a potential risk to the sustainability of programs in the latter. The chemical industry is prominent, with diversification in Atlántico and a focus on the petrochemical sector in Bolívar. Graduates of chemical engineering in the Caribbean region have diverse career opportunities with employability ranges between 50 % and 80 %. Besides, Clusters and CUEEs are important initiatives that guide collaboration within the AIGS alliance, utilizing methodologies for strategic management and participatory projects to receive state funding for developments through Science, Technology, and Innovation. This study's results demonstrate that the practice of chemical engineering in the Caribbean region is harmonized with the region's strategic goals, cultivating socio-economic benefits through collaborations between companies and universities. Furthermore, these findings offer direction to higher education institutions, particularly private ones, encouraging proactive efforts to secure resources for projects. These initiatives, in turn, create avenues to expand educational opportunities for economically disadvantaged students.

Keywords: action field, chemical engineering, job offer, quadruple alliance.

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Resumen

La ingeniería química es crucial en la sociedad y puede contribuir a la colaboración entre la academia, la industria, el gobierno y la sociedad (AIGS) para promover proyectos sostenibles y la transferencia de conocimiento en la región del Caribe en Colombia. Este estudio examina el impacto de la ingeniería química en la región, incluyendo la oferta de programas, indicadores de los programas de ingeniería química, mercado laboral y oportunidades para proyectos con impacto social. Se han identificado cuatro instituciones públicas y privadas, cada una de las cuales ofrece programas de estudio integrales de 10 semestres diseñados para cultivar tanto la experiencia técnica como la educación humanística en futuros ingenieros químicos. Estos programas tienen como objetivo proporcionar a los estudiantes las herramientas necesarias para abordar los apremiantes desafíos de la sostenibilidad. El plan de estudios está estructurado en componentes distintos: fundamentos (34 %), bases de la ingeniería (17 %), profesional (39 %) y humanidades (11 %). Sin embargo, han surgido disparidades en los números de inscripción de estudiantes entre instituciones públicas y privadas, lo que plantea un riesgo potencial para la sostenibilidad de los programas en estas últimas. La industria química es prominente, con diversificación en Atlántico y un enfoque en el sector petroquímico en Bolívar. Los graduados de ingeniería química en la región caribeña tienen diversas oportunidades de carrera, con tasas de empleabilidad que oscilan entre el 50 y el 80 %. Además, los clúster y los CUEEs son importantes iniciativas que guían la colaboración dentro de la alianza AIGS, utilizando metodologías para la gestión estratégica y proyectos participativos para recibir financiamiento estatal para desarrollos a través de Ciencia, Tecnología e Innovación. Los resultados de este estudio demuestran que la práctica de la ingeniería química en la región caribeña armoniza con los objetivos estratégicos de la región, cultivando beneficios socioeconómicos a través de colaboraciones entre empresas y universidades. Además, estos hallazgos orientan a las instituciones de educación superior, especialmente las privadas, a fomentar esfuerzos proactivos para asegurar recursos para proyectos. Estas iniciativas, a su vez, crean posibilidades para expandir las oportunidades educativas para estudiantes en situación de desventaja económica.

Palabras clave: campo de acción, cuádruple alianza, ingeniería química, oferta laboral.

INTRODUCTION

The dynamics of the current world present new challenges, such as energy acquisition, food security, and environmental conservation, among others. These challenges make it necessary to change the paradigms of educational systems in order to have professionals who are up to these challenges [1]. Universities are the ideal entities to promote these changes, as through research and education, the application of science can be driven in all fields of knowledge, especially in the field of engineering [2]–[4].

Higher education institutions, responsible for training chemical engineers, become a fundamental pillar in promoting processes of change and improvement in industrial production of materials and services. Additionally, they provide a space for reflection to propose solutions to the technical challenges posed by renewable energy acquisition, environmental conservation, and societal advancement [5].

Chemical engineering, within academy, constantly seeks to ensure that curriculum programs are appropriate [6] and meet the challenges demanded by society [7], industry [8], and regulations [9]–[12]. These requirements are also aligned with the achievement of the Sustainable Development Goals (SDGs) proposed by the United Nations (UN) [13]. Optimization of physicochemical and biological processes plays a fundamental role in addressing challenges such as affordable and clean energy, clean water and sanitation, and climate action, primarily [14].

According to the above, academic programs must be constantly reviewed and adjusted from a holistic perspective. They should consider the four sectors that support sustainable development: academy, industry, government, and society (AIGS) [15]. This approach aims to generate knowledge-based policies and experiences that underpin decision-making towards the implementation of models and methodologies for improving various social, economic, and environmental aspects of the region [16]–[18]Traditionally, the academic and industrial sectors have interacted under a linear development model, in which academia focuses on basic research, and industry scales up the results for applications and innovations, often driven by economic interests [19]–[22]. It was not until the year 2000 that the so-called Triple Helix model was introduced, which includes the interaction with the government to create national systems of innovation and development. However, the primary emphasis of the Triple Helix model continues to be on the economy. More recently, it has become necessary to expand the vision to a Quadruple Helix, which directly involves society in the collaboration between academy, industry, government, and the social sphere.

Internationally, there are several experiences of applying the Quadruple Helix model[23]–[25]; however, these experiences reveal challenges such as equal participa-

tion of the four sectors, inclusion of minority groups, the industry's limited interest due to lack of immediate economic returns, and ineffective communication between sectors. In Colombia, since 2003, cooperation among the four sectors has been promoted through University-Industry-Government-State Committees (CUEEs), located in different regions of the country. The CUEEs aim to foster the comprehensive development of the four sectors through the implementation of technological solutions that seek to have a positive impact on society.

The Quadruple Helix AIGS model should be leveraged by chemical engineering programs, as it allows for the enhancement of program-specific knowledge by promoting multisectoral and interdisciplinary work. In this way, chemical engineers can develop a more comprehensive approach that generates high-value products, processes, and services in support of socioeconomic progress. The present study analyzes the state of chemical engineering in the Colombian Caribbean region, as this area of the country has a significant impact and importance in the national chemical industry. The aim is to study the importance and degree of participation of chemical engineering in the Quadruple Helix in the Colombian Caribbean region. This involves comparing the educational offerings of universities, companies, and the prospects for career development of chemical engineers in both the private and public sectors, along with the projects developed. This will help identify strengths, areas for improvement, and threats in the chemical engineering programs of the Caribbean region, as well as how the AIGS alliance is promoted for economic and social development.

METHODOLOGY

The diagnosis of the current state of chemical engineering in the Colombian Caribbean is approached from the AIGS model [26], based on the premise that the collected information will allow for the identification of gaps, improvement opportunities, and strategies to strengthen education and competencies in the training of chemical engineers. For this purpose, a systematic study was carried out [27], [28], which involved an organized search process using various bibliographic resources that address the background and information from the four sectors that form the alliance: academy, industry, government, and society (Figure 1). For the academic sector, the aim is to establish and characterize the offerings of the chemical engineering program in the Colombian Caribbean region [28]. The research examined the study curricula offered by chemical engineering programs within the region, drawing from the content available on the individual university websites. Alongside this, pertinent data encompassing the enrollment, admissions, and graduation figures over the preceding five years (2017-2022) for each program were meticulously compiled. This information was systematically sourced on an annual basis from the National Higher

Education Information System (SNIES) [29], subsequently undergoing an averaging process to ensure accurate and concise data representation [30].

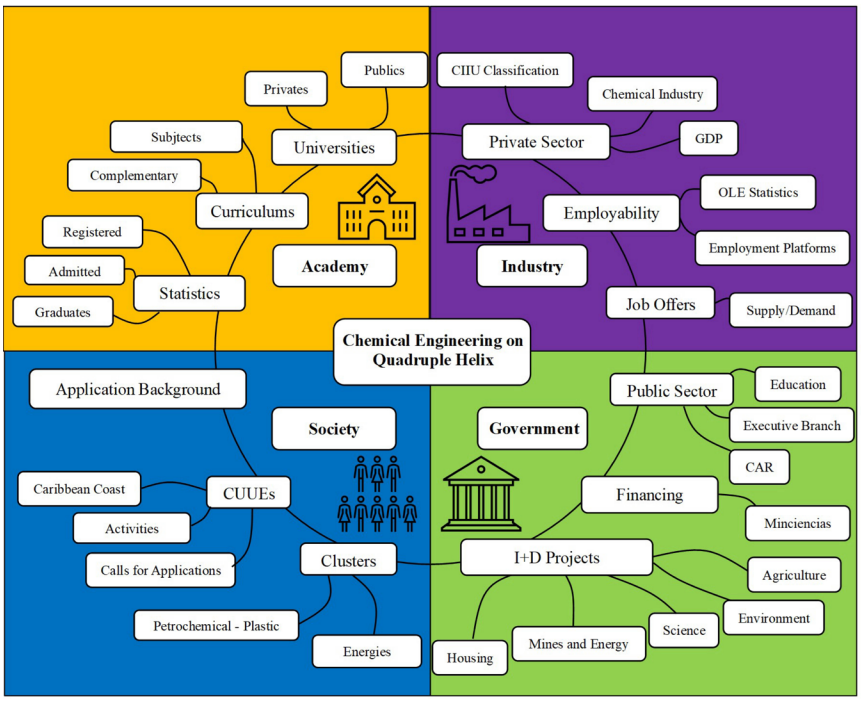

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FIGURE 1. INVESTIGATED TOPICS FOR THE ACTORS OF THE ACADEMY-INDUSTRY-GOVERNMENT-SOCIETY (AIGS) ALLIANCE

Then, to establish the training gap of the chemical engineering program in relation to the demand from the labor or productive sector, the analysis incorporated the latest economic and commercial departmental reports sourced from the Ministry of Commerce, Industry, and Tourism. In tandem with this, the study also utilized the most recent directory of companies categorized by department, acquired from the National Administrative Statistics Department (DANE). These companies were systematically classified based on the CIIU codes, enhancing the comprehensiveness and relevance of the gathered data. The aim is to identify the economic sectors associated with the core knowledge of chemical engineering [31].

Subsequently, in order to ascertain the employability of professionals in the field of chemical engineering, the study involved compiling and quantifying job openings targeting chemical or process engineers. These openings were sourced from companies operating within the sectors previously identified. To accomplish this, a systematic search was conducted on online job portals such as "https://elempleo.com/co"

and "https://computrabajo.com", as well as government contracting platforms like "https://www.cnsc.gov.co/". This search was performed on a weekly basis spanning the period from June 2022 to date.

In exploring the societal implications of chemical engineering, the task is not easy. For this reason, a process was undertaken to organize and document projects within the field of chemical engineering that could facilitate collaborative initiatives with the dual goals of advancing research and creating social impact. To achieve this, a search was conducted across various digital platforms, primarily those of the government, because they have the responsibility to improve the quality of life for people and protect the environment. This search encompassed the examination of online resources, including the websites of University-Industry-Government-State Committees (CUEEs), the Colombian cluster network, official calls for proposals by the Ministry of Science, Technology, and Innovation (Minciencias) [32], comprehensive investment mapping provided by the National Planning Department [33], as well as the analysis of budgetary allocations and implementation records for national investment projects overseen by the Ministry of Mines and Energy during the period from 2018 to 2022 [34].

RESULTS AND DISCUSSION

Chemical engineering program offerings

Four Chemical Engineering programs were identified in the Caribbean region, offered by the University of Atlántico (UA), University of San Buenaventura - Cartagena Section (USB), University of Cartagena (UdeC), and Technological University of Bolívar (UTB), established in 1941, 1992, 2000, and 2016, respectively. According to the above, chemical engineering education in the Caribbean region is concentrated in Barranquilla and Cartagena. This is due to their strategic geographical position, which has fostered the development of the basic chemical and petrochemical industries, leading to increased dynamics in chemical exports and imports through the ports of both cities [35].The offered programs share similarities in their academic organization. They have a duration of 10 semesters, with the number of subjects ranging from 57 to 66 per program and an academic credit range between 170 and 175. The distribution of subjects across the core areas of study is shown in Figure 2. The foundational component includes subjects such as mathematics, chemistry, physics, statistics, and programming. The engineering basics cover subjects like mass balance, physical chemistry, fluid mechanics, thermodynamics, among others. The main professional subjects focus on unit operations, process control and simulation, and

plant design. Finally, the humanities component includes various subjects ranging from religious culture, constitution, ethics, and languages.

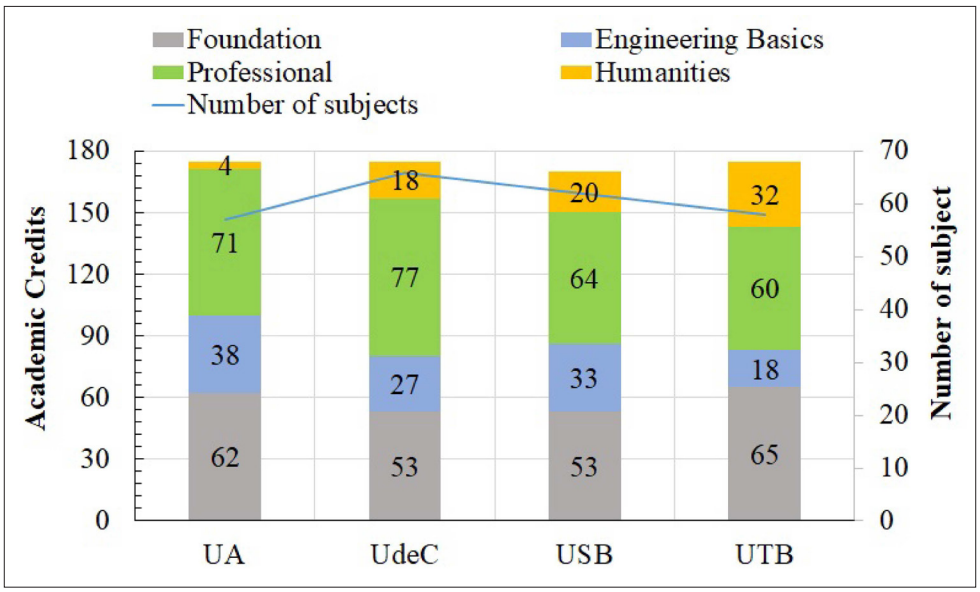

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Figure 2. Distribution of credits by components (upper part of the graph, left axis), total number of subjects (right axis) in each university (bottom axis). * Includes 6 to 10 credits of English

The credit allocation corresponds to the time dedicated to each subject, which aligns with the competencies that students should develop according to each university's mission and the proposed profiles defined in the educational project of each program. In this sense, significant differences are observed in the distribution of credits within each program. Figure 2 illustrates that public universities UdeC and UA allocate more credits to professional and basic engineering subjects, with 109 and 104 credits, respectively. In contrast, private universities USB and UTB assign 97 and 78 credits, respectively, to these components. This suggests that public universities may emphasize an occupational profile for graduates with a stronger emphasis on research and process design, while private institutions may prioritize a fundamental understanding of processes and potentially lean towards management roles. This alignment is consistent with the missions and management styles of these institutions, as public universities typically benefit from numerous research groups, superior infrastructure, and more substantial resources for equipment and laboratories, largely funded by the Colombian state. Conversely, private institutions rely primarily on their own resources and enrollment, resulting in more limited investment

budgets for specific areas of chemical engineering. This distinction is especially pronounced in the case of UTB, where the program contains the fewest credits in the technical professional component due to its shorter duration.

Moreover, concerning humanities subjects, UdeC has the lowest number of credits (4). This is because its curriculum is designed with a significant percentage of flexible components, allowing students to choose between humanities or professional areas.

Additionally, it's worth noting that both private universities require mandatory professional internships, while they are optional in public universities. However, in terms of technical knowledge relevant to chemical engineering, encompassed by engineering basics and professional subjects, both public universities and USB allocate a higher proportion of credits compared to UTB, which focuses more on laying the foundational engineering principles.

The SNIES statistics provided in Table 1 reveal the average enrollment, admissions, and graduation figures for IQ (Institution's acronym) across various institutions over the past 5 years. Noteworthy variations are evident based on geographical location and institutional characteristics. Notably, a glaring contrast exists in the application numbers for the chemical engineering program between Barranquilla and Cartagena. Surprisingly, Barranquilla, with just one university offering the program, witnesses double the number of applicants compared to Cartagena, which boasts three such programs. This incongruity raises questions, especially since Cartagena provides a greater program selection in this field compared to Barranquilla. Potential explanations for this divergence include demographic differences, higher corporate presence (refer to supplementary materials), and the historical trajectory of University of Atlántico, the pioneering institution to introduce Chemical Engineering in Colombia.

Table 1. Statistics from the System for Higher Education, average of periods between 2017 and 2021 [29]

State	Atlántico	Bolívar		
UNIVERSITY	AU	USB	UdeC	UTB
Enrolled	549,3	26,8	202,4	40,3
Admitted	100,8	25,4	57,7	30,3
Admission rate	28%	92%	37%	85%
Enrolled in the first semester	86,7	12,6	40,9	20,7
Percentage of enrolled	86,0%	49,6%	70,9%	68,3%
Graduates	47,4	13,6	33,5	0,6
Graduation rate/enrolled	55%	108%	82%	3%

Source: Authors.

On the other hand, according to the nature of the institution, it is observed that the average number of enrollees in public institutions is significantly higher than in private institutions, however, public institutions do not have sufficient coverage to meet all the demand for registered, so they only admit around 30 % of the applicants. Due to this, the percentage of the admission rate, calculated as the ratio between admitted and enrolled students per semester, shows that private institutions (USB and UTB) have a higher admission rate than public ones. This phenomenon can generate a segregation and impact on the quality of the programs, since by having a limit of quotas the UdeC and the UA, promote the competitiveness in the applicants, for which, in general, these institutions will have students with better academic profile than private ones. The factors that influence this decision are primarily the cost of tuition, which is based on the student's socioeconomic level and is generally lower than that of the two private universities included in this study. Furthermore, the two IQ programs offered by public universities are accredited with high quality standards and have greater infrastructure for conducting experimental practices and research. Additionally, these universities have the advantage of being better positioned in research and innovation rankings [36], with a 30-position difference between public and private universities.

In coherence with what was previously discussed, the number and percentage of students enrolled in public institutions is much higher than in private ones. Likewise, in terms of the number of graduates, it is evident that public universities have more graduates than private ones, since public education is subsidized by the national government, while private universities depend on student enrollment rates. Due to this, there is a decrease in the number of students enrolled in the USB, while the UTB shows a continuous growth in the number of students enrolled as it is the newest program of all. However, the number of students enrolled remains worrisome as they are below break-even, which could indicate that these two programs will disappear in the next few years if they are not financially sustainable.

This indicates that private universities have not been able to attract the attention of students who are unable to enter public universities, mainly due to economic factors, but also because students may not be aware of the benefits of a more personalized education. Additionally, private universities adhere to a regular academic calendar that ensures the completion of curriculum activities within the scheduled timeframe, while in public universities, this depends on external factors.

The presented landscape raises an alert for private educational institutions in the city of Cartagena, as despite having a thriving industry that could require chemical engineers and three available academic programs, these institutions currently experience a deficit in student enrollment within the program. Another reason is the low

interest of young people in fields related to chemical engineering, and in general, in STEM (Science, Technology, Engineering and Mathematics) programs [37]. This could be explained by the perceived difficulty of the subjects studied in these areas, coupled with a lack of knowledge about the fields of action and application of chemical engineering, especially in Cartagena, where the city is associated with tourism, while Barranquilla is more linked to the industrial sector [38], [39].

One strategy to improve the enrollment rate in IQ programs at private universities could focus on increasing student interest and participation in STEM subjects from their secondary education[40]–[42], combined with promoting awareness of the industrial growth in Mamonal area in Cartagena and the employment possibilities that engineers would have. Additionally, it is evident that given the average income level of Cartagena residents, it is necessary to strengthen financial systems such as credit and scholarships that enable access to higher education in private institutions for students who cannot enter public institutions.

Labor demand

The chemical industry in the Colombian Caribbean region significantly contributes to the economy of the region and the country. It has experienced significant growth in recent years, thanks to infrastructure and technology investments by the government and the private sector (See support material). This is reflected in its industrial production, Figure 3 (A) shows the distribution of industrial production in these departments, according to the Classification of Economic Activities (CIIU) where the chemical-related sector accounts for 99.5 % of the total industrial production in the Bolívar department and 54.3 % in the Atlántico department. Additionally, it can be observed that in Bolívar, 55.9 % of the industrial production is related to the petrochemical industry, compared to 6.5 % in the Atlántico department. This is due to the presence of the second largest refinery in the country in Cartagena. On the other hand, Barranquilla has a focus on the production of food (25.8) and other manufacturing industries (45.7) being the main pharmaceutical. Additionally, Figure 3 (B) shows the number of companies per economic activity in Bolívar (385) and Atlántico (808). Atlántico has more than twice as many companies in the chemical sector as Bolívar. However, this does not proportionally represent the difference in the gross domestic product (GDP) of the departments. The GDP figures reported by DANE [42] amount to US$ 13,975,352 in the Atlántico department and US$ 11,139,994 in Bolívar. Therefore, it can be inferred that the companies present in the Bolívar department are larger and have a greater economic impact than those in Atlántico, with higher value-added products such as fertilizers and fuels.

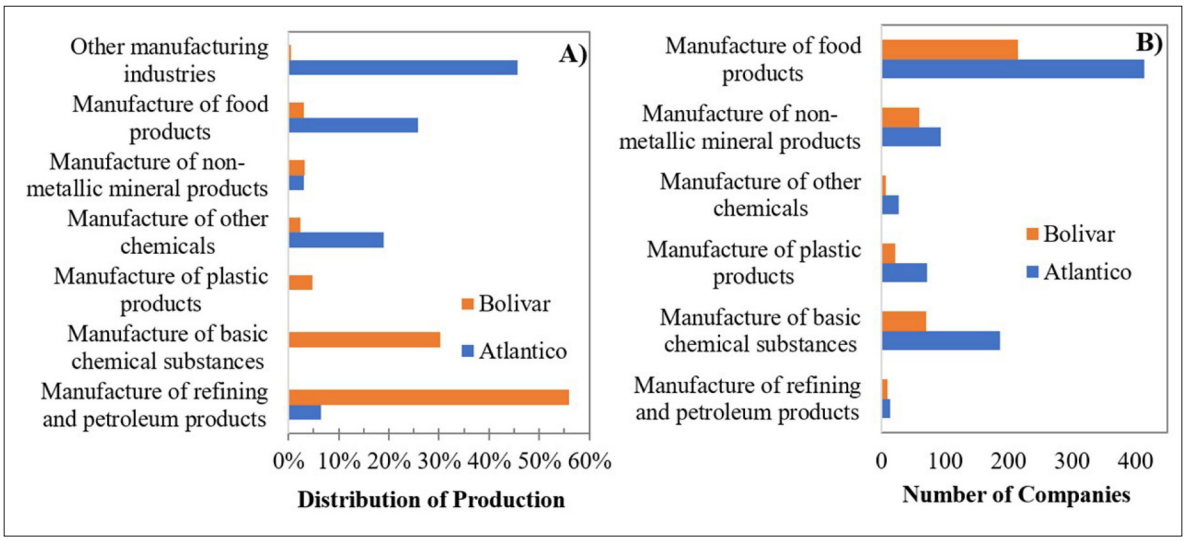

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FIGURE 3. INDUSTRIAL PRODUCTION (LEFT) AND NUMBER OF COMPANIES (RIGHT) IN BOLÍVAR AND ATLÁNTICO RELATED TO THE CHEMICAL INDUSTRY ACCORDING TO THE CLASSIFICATION OF ECONOMIC ACTIVITIES (CIIU)

The employability of chemical engineers graduating from institutions in the Caribbean region was evaluated based on the information reported by the Higher Education Labor Market Observatory (OLE). Figure 4 shows the data corresponding to the percentage of graduates who contribute as dependents to the Integral Social Security System, meaning that they are employed by an institution. It can be observed that, in general, the employability of chemical engineering graduates in the Colombian Caribbean region ranges between 50 % and 80 %. Additionally, the impact of the pandemic is evident in the decrease in employed engineers for all higher education institutions, although this was more critical for private universities. However, it should be noted that the number of graduates from private institutions is much smaller than that of public institutions in this study.

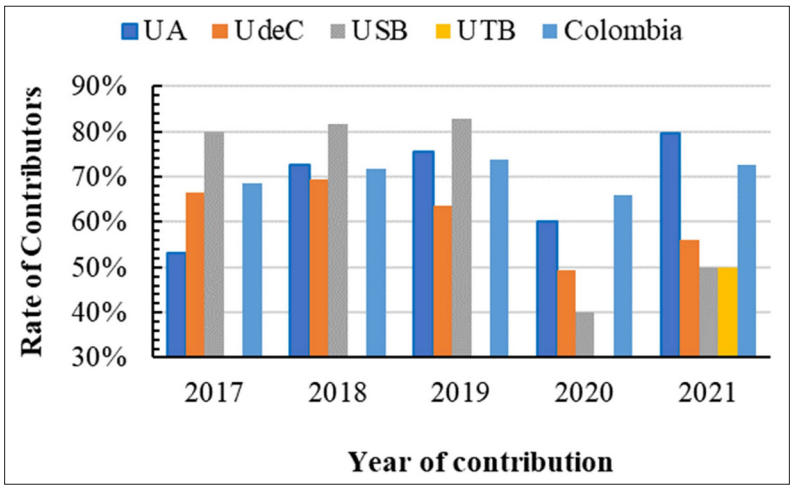

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FIGURE 4. CONTRIBUTION RATE OF CHEMICAL ENGINEERING GRADUATES IN RECENT YEARS FOR UNIVERSITY OF ATLÁNTICO, UNIVERSITY OF CARTAGENA, UNIVERSITY OF SAN BUENAVENTURA, TECHNOLOGICAL UNIVERSITY OF BOLÍVAR AND COLOMBIA

In addition to the above, the job opportunities related to chemical engineering were determined in the departments of Bolívar and Atlántico. This was done by quantifying the availability of vacancies in job portals such as LinkedIn, Computrabajo, El Empleo, and the National Employment Agency from June 2022 to May 2023 (see support material). The results show that the Atlántico department has an offer that is almost double the number of vacancies in the Bolívar department, with an average of 72 and 33 vacancies, respectively. The predominant job requests are distributed in the areas of food manufacturing (20.21 %), business services (19.15 %), IT services (13.83 %), education (9.57 %), and manufacturing of other chemicals (8.51 %). When comparing these data with the average number of graduates per year (see Table 1), it can be established that the job offer in Atlántico exceeds the rate of graduates, resulting in a positive gap in job opportunities in this department. In contrast, in the Bolívar department, the supply-demand margin is much narrower, which may represent a restriction in terms of employability. This is consistent with the observed difference between the two departments in terms of the number of companies.

In addition to the job opportunities in private entities, chemical engineers have a high potential to engage in professional activities in the public sector, within different government agencies [43]. This goes against the perception that public jobs are primarily associated with administration or careers focused on political sciences. This is evident from the data reported by the CPIQ, which shows that the employment rate of chemical engineers in the private sector nationwide is 82%, compared

to 10 % in the public sector [44]. An example of this is the limited participation of chemical engineers in legislative bodies, possibly due to the limited knowledge of public policy management. So far, records indicate only two former senators who were chemical engineers [45].

This paradigm has been changing due to the need to incorporate technical and specialized knowledge into the management and development of public policies, such as those related to the environment and energy management. To meet these needs, it has also become necessary for engineers' education to include subjects related to soft skills, which allow for the development of project management and resource administration abilities, in addition to technical knowledge [46]. This way, chemical engineering professionals can be more competitive. Most universities have addressed this by incorporating subjects from the humanities component and courses in administration and management, which are included as elective courses, promoting flexibility and adaptability [47]. This could be a differentiating factor for professionals, enabling a proper balance between technical expertise and analytical skills for solving complex engineering problems, thus facilitating chemical engineers' contribution to the proper functioning of the quadruple helix [48]–[51].

The background of job offers for chemical engineers in Colombia shows that within the executive branch, up to 2593 technical or administrative positions can be offered. However, this study did not consider other institutions that are part of the executive branch, such as the education sector, public service provision, hydrocarbon generation, and environmental control and regulation entities. Therefore, Table 2 presents the complete results of job offers for chemical engineers in the public sector in the region. This table provides an overview of the available positions within the National Civil Service Commission, the governing body responsible for managing the Hiring System for roles within the Colombian public sector, spanning various governmental entities. Within the scope of this research, one of the most significant recruitment drives pertains to the Special Teaching Career System, which supplies educators to institutions in the field of basic education.

Additionally, this platform also lists job openings within regional autonomous corporations, which oversee and regulate activities pertaining to environmental conservation and care. However, it's worth noting that there are fewer opportunities for chemical engineers in other entities such as DIAN (National Tax and Customs Directorate), departmental secretaries, and similar organizations.

The positions detailed in the table specifically target chemical engineers. Teaching roles encompass fields such as chemistry, physics, environmental sciences, and mathematics, as well as administrative roles within the departments of Bolívar and Atlántico. Vacancies within higher education institutions are typically posted on

the respective websites of these institutions and pertain to various engineering departments that seek candidates with profiles matching those of chemical engineers. Lastly, for positions at Ecopetrol, relevant information can be sourced directly from the company's official portal (https://jobs.ecopetrol.com.co/).

These results indicate that vacancies in secondary education account for 64.8 % of the total vacancies. This sector provides an opportunity for recent graduates as no experience or postgraduate studies are required. In addition, the selection process is carried out through a qualifying knowledge examination, with topics related to logical and technical reasoning, where engineers have an advantage over professionals in teaching degrees.

Table 2. Job opportunities available for chemical engineers in the Caribbean region during the year 2023 [52], [53]

Sector		Number of vacancies per state								Total
		Bolívar				Atlántico				
Education	Medium	C	P	E	M	C	P	E	M	
		57	14	80	210	18	68	29	194	670
	High	4				0				4
Executive Branch		168				156				324
Regional Autonomous Corporation		CARDIQUE		CARCSB		CRAUTONOMA				25
		12		3		10				
Ecopetrol		11				0				11
Total		559				475				1034

Source: Authors.
* C: Natural Sciences - Chemistry; F: Natural Sciences – Physics; E: Natural Sciences and Environmental Education; M: Mathematics, CARDIQUE: Regional Autonomous Corporation of the Dique Canal; CARCSB: Regional Autonomous Corporation of Southern Bolívar and CRAUTONOMA: Regional Autonomous Corporation of the Atlántico.

In contrast, vacancies in other public entities generally require experience and postgraduate studies. For example, the executive branch, which accounts for 31.3 % of the total employment opportunities, requires knowledge and postgraduate studies in project management, public administration, and/or quality management, making it more challenging to enter the job market, especially considering that chemical engineers must compete with 55 different disciplines. In other entities, which have a lower percentage, the requirements are higher due to the need for postgraduate education, proficiency in a second language, and specific experience ranging from 2 to 15 years. Examples include vacancies in higher education institutions, positions in Ecopetrol, and recruitment processes in Regional Autonomous Corporations (CAR), which account for approximately 3.9% of the total vacancies.

The displayed vacancies are not constant because these positions depend on the specific needs of the entities and the policies of the current governments. For example, it was found that there had been no recruitment processes in the secondary education sector since 2019. Another case to consider is the public utility companies, which currently do not have any vacancies available. However, they have the potential to offer 387 positions related to solid waste management, wastewater treatment, and water purification. This demonstrates that the public sector represents an important niche for the development and work of a chemical engineer. Future professionals who wish to work in the public sector will need to deepen their knowledge of project management, public policy, and pedagogy, which can be strengthened through elective and complementary professional subjects offered by the analyzed universities.

Society

Due to its capacity to transform resources, chemical engineering has a strong impact on society, including environmental, energy, and material production aspects, among others. The quadruple alliance seeks to channel the efforts of academy, industry, and government for the benefit of society. In Colombia, there are eleven University-Industry-Government-State Committees (CUEEs) operating throughout the country. In the case of the Caribbean Coast, a CUEEs was established in 2007, which includes four departments: Atlántico, Bolívar, Córdoba, and Magdalena. Through this initiative, 8 University-Industry Workshops, two innovation business rounds, five meetings, and 17 operational committee meetings have been held since its inception. The two most recent activities of this alliance were the meeting on July 2, 2021, in Atlántico, and the call to support initiatives addressing social issues in Cartagena, named "Sustainable City Cartagena," presented on February 8, 2023. However, despite these activities, the search conducted reveals that the CUEEs of the Caribbean Coast does not have a record of completed or ongoing projects that would allow for assessing its impact, which may indicate deficiencies in its execution or ineffectiveness.

Another initiative like CUEEs is the sectoral clusters, which bring together interconnected actors in a specific field of knowledge or production. The work of these networks is led by the Chambers of Commerce in each department and involves the participation of different actors from the AIGS. Currently, there are over 120 cluster initiatives in the country, with six located in the department of Atlántico and two in the department of Bolívar, among which the Energy Cluster in Atlántico and the Petrochemical-Plastics Cluster in Bolívar, directly relevant to chemical engineering, stand out. As a result of the work of these clusters, 17 projects focused on various areas have been identified, including the transition and energy efficiency, the promotion of the Caribbean region as a development center for the use of hydrogen as an energy

vector, the reduction of environmental impact in production processes, productivity improvement, general population education, and human capital formation, among others (see support material). These initiatives are of great importance as they directly impact the processes of the four actors in the quadruple helix and integrate the efforts of each of them. However, methodologies for participation and commitment from each alliance member should be strengthened to achieve more effective work.

Another way for chemical engineers to participate and have an impact on society is through application or research projects. In Colombia, notable sources of funding for these purposes include the General Royalties System (SGR), the General National Budget (PGN), and the budget of each department (TER). Table 3 summarizes the results of recent projects related to chemical engineering that have been funded by the mentioned sources in the departments of Atlántico and Bolívar over the past five years. The results show that the SGR is the predominant source of project funding in both departments. It is also worth noting that the number of projects in Atlántico is double that of Bolívar, despite Bolívar having a larger territorial extension. This demonstrates that the department of Atlántico exhibits better development dynamics, including economic, academic, and social aspects, which have been driven by the local government.

Table 3. Number of projects supported by the Ministry of Science, Technology, and Innovation (Minciencias) in the Caribbean region, in the sectors with the greatest impact on chemical engineering for the period 2018-2023

State	Atlántico			Bolívar			TOTAL
Sector	PGN	SGR	TER	PGN	SGR	TER	
Agriculture and rural development	0	6	1	0	5	1	13
Environment and sustainable development	0	5	10	0	8	0	23
Science, technology, and innovation	0	11	0	0	3	0	14
Mines and energy	1	1	3	0	1	0	6
Housing, city and territory	0	2	10	0	1	6	19
TOTAL	1	25	24	0	18	7	75

Source: Authors.
* PGN: General Budget of the Nation; SGR: General Royalties System; TER: Territory.

It is worth noting that the environment and sustainable development sector has a higher number of projects in both departments, focusing on energy efficiency and conservation (see annex). On the other hand, projects in the mining and energy sector are focused on topics related to energy transition. Despite having a lower number of projects, this sector accounts for approximately 80 % of the total budget.

This indicates coherence between the academic and governmental sectors as implementers and funders, respectively, aiming to contribute to the benefit of society and the SDGs. The previous projects show limited participation from the private sector; however, Minciencias is currently promoting the integration of companies in the formulation and implementation of projects. In order to achieve this, incentives are offered to foster interdisciplinary, interinstitutional, and intersectoral partnerships in the aforementioned strategic sectors. The goal is to achieve results of greater impact on the socioeconomic development of the region.

However, in order to participate effectively in these calls, it is imperative that alliances and projects between institutions are formulated in advance. This is because the timeframe between the opening and the submission of technical proposals is not sufficient to carry out the administrative management involved in the government policy of the alliances and all the associated documentation. This includes meeting legal requirements and uploading all the documents on the ministry's website for the application to the call [54], [55].

Another institution that has fostered projects to improve society's quality of life is the Ministry of Mines and Energy, as they are required by law to develop projects that provide energy connection to households and enhance its supply. In these projects, chemical engineers can contribute to national investments (Table 3) in the environmental, energy, hydrocarbon, and mining sectors. It can be observed that the two sectors with the highest investment budget in the last five years (2018-2022) are the energy sector (73.4 %) and the hydrocarbon sector (24.6 %). This aligns with the country's needs for a better and environmentally sustainable energy connection. The Colombian Caribbean coastal region will benefit in the coming years, as the current government will invest more, around 10 trillion dollars, in energy transition. This represents a 56.6% increase compared to previous years. The fundamental goal is to progress towards a fair, sustainable, and gradual energy transition that ensures the country's energy sovereignty.

Efforts are estimated to focus on clean energy and decarbonization projects; the gradual substitution of fossil fuel demand; greater energy efficiency; the review and potential relaxation of regulations to expedite clean energy generation, and the reindustrialization of the Colombian economy [56]. This presents an excellent opportunity for educational institutions to present projects that educate chemical engineers about these initiatives and for private industries to engage in this transformation. Implementing the quadruple alliance model would be an effective way to benefit society.

Among the main energy projects that will directly impact the departments of Bolívar and Atlántico, and will require collaboration in the quadruple alliance, are the

expansion of the regasification plant in Barú, Bolívar [57], and the large-scale electric energy storage project located in Atlántico [58].

Table 4. Investment Projects in the Mining and Energy Sector at the National Level between 2018 – 2022 [$USD]

Year	Investment by Sector (Number of Projects by Sector)			
	Environmental	Energy	Mining	Hydrocarbon
2018	2.068.524 (4)	555.352.896 (7)	2.676.914 (7)	227.431.441 (8)
2019	5.691.954 (5)	633.178.536 (5)	29.167.352 (12)	193.690.879 (7)
2020	3.249.773 (4)	547.676.561 (7)	13.791.702 (8)	134.567.472 (7)
2021	2.720.961 (4)	807.581.993 (11)	11.053.463 (6)	198.512.609 (7)
2022	3.301.365 (4)	644.046.909 (11)	12.251.747 (7)	312.171.683 (9)
TOTAL	17.032.577 (21)	3.187.836.895 (41)	68.941.178 (40)	1.066.374.084 (38)

Source: Authors.

Finally, we would like to highlight the progress of the Quadruple Alliance that has been achieved in Colombia, comprised of the company Cementos Argos, EAFIT University, Minciencias, and the Cartagena community. This group, led by the private sector along with academics, civil society, and the government, has demonstrated the viability of harnessing microalgae to capture CO_2, and furthermore, it is feasible to produce biofuels from them. This project has been awarded the Alejandro Ángel Escobar National Science Prize, which recognizes the significant work carried out by the alliance and its members. They affirm that success lies in generating collaborative innovation processes to seek models with technical and financial viability, and that this can only be achieved through the contribution of all and a networked effort [19], [23], [25], [59], [60]. From this successful experience, it can be stated that a leader is needed for the alliance to function correctly, as they must possess technical knowledge, industry understanding, and skills to comply with regulations and improve working conditions for the workers. This leader could be a chemical engineer, as they have the necessary training to take control and help implement the quadruple helix alliance with the aim of promoting sustainable development and achieving the Sustainable Development Goals (SDGs).

CONCLUSIONS

The findings of this study validate the role of chemical engineers within the quadruple helix AIGS alliance as integrators and promoters of the socio-economic develop-

ment of the Colombian Caribbean region. This is achieved through the formulation and implementation of sustainable projects, as well as knowledge transfer processes.

In the realm of academy, a noteworthy disparity becomes evident, with a nearly 9 % variance between public and private institutions concerning the emphasis placed on fostering soft and humanistic skills. Private institutions allocate approximately 15 % of their curriculum to these skills, whereas their public counterparts dedicate only 6 % to them. In contrast, when it comes to subjects within the professional and basic engineering domains, public universities assign 61% of their curriculum, while private universities allocate 50 %. This divergence serves as a key factor that facilitates the integration of chemical engineers into cross-sectoral teams. However, it's crucial to acknowledge a significant enrollment gap between the two types of institutions, which could potentially pose challenges to the long-term viability of chemical engineering programs within private universities. These institutions have not been able to attract the population of applicants who are unable to enter public institutions. Furthermore, it was evident that chemical engineering education is centralized in the capital cities of the departments, with little diffusion and awareness of chemical engineering and its impact in the regions among high school students and the general population.

The Caribbean region has a strong inclination towards the chemical industry; however, in Atlántico, there is a diversification of this industry, whereas in Bolívar, there is a clear concentration in the petrochemical sector. In this regard, chemical engineering programs in Atlántico should strengthen competencies in processes and develop different lines of specialization. In contrast, in Bolívar, there should be an emphasis on petrochemical processes that are oriented towards the implementation of technologies promoting efficiency, energy transition, and sustainable development.

To achieve the aforementioned goals, it is necessary to establish effective channels for knowledge transfer among the stakeholders of the quadruple helix alliance. This process should be driven by initiatives such as Clusters and CUEEs; however, quantifiable results of their work are not evident. An alternative to address this could be the creation of a single organization that leads and directs the coordination of participants from both initiatives, using strategic management methodologies that facilitate project development and impact measurement. This way, projects can be eligible for funding from Minicomics through the Science, Technology, and Innovation calls, which finance projects aligned with the strategic axes of the regions, involving companies and universities, under state funding.

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