CienciAmérica: Revista de Divulgación Científica de la Universidad Tecnológica Indoamérica
ISSN: 1390-9592
ISSN: 1390-681X
cienciamerica@uti.edu.ec
Universidad Tecnológica Indoamérica
Ecuador

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ENERGY AND ENVIRONMENTAL PERFORMANCE INDICATORS AT UPSTREAM OIL FACILITIES IN ECUADOR

CienciAmérica: Revista de Divulgación Científica de la Universidad Tecnológica Indoamérica, vol. 13, no. 2, https://doi.org/10.33210/ca.v13i2.473, 2024, July-December
Universidad Tecnológica Indoamérica
Ecuador

CienciAmérica (2024) Vol. 13 (2)
ISSN 1390-9592 ISSN-L 1390-681X

Energy and environmental performance indicators at upstream oil facilities in Ecuador

Indicadores de rendimiento energético y medioambiental en las instalaciones petrolíferas de Ecuador

Indicadores de desempenho energético e ambiental em instalações petrolíferas a montante no Equador

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Fecha de recepción: 12 de julio de 2024.
Fecha de aceptación: 28 de octubre de 2024.

ABSTRACT

The study evaluates the energy and environmental performance of Ecuador's upstream oil facilities between 2015 and 2020, focusing on major extraction blocks. By analyzing data on oil, gas, and water production, fossil fuel consumption, and electricity usage, key performance indicators were developed to assess efficiency and environmental impact. The findings revealed disparities in energy efficiency, with Block 43-ITT being the most efficient at 7.82 kWh per barrel, while Block 57-LB was the least efficient at 31.41 kWh per barrel. The study emphasizes that maturing oil fields require more energy and emit more greenhouse gases, underlining the necessity for sustainable energy practices. EP Petroecuador's initiatives, such as substituting fuel and integrating renewable electricity, led to a reduction of approximately 540 kTons of CO2 emissions by replacing 163.32 million gallons of diesel with low-carbon fuels and renewable electricity. These findings serve as a baseline for optimizing energy use and reducing emissions, offering valuable insights for policymakers and industry leaders to adopt data-driven strategies that enhance energy efficiency and minimize environmental impact in Ecuador's oil sector.

Keywords: Energy consumption, petroleum industry, power generation, energy indicators, carbon dioxide emissions.

RESUMEN

El estudio evalúa el rendimiento energético y medioambiental de las instalaciones petrolíferas upstream de Ecuador entre 2015 y 2020, centrándose en los principales bloques de extracción. Mediante el análisis de datos sobre la producción de petróleo, gas y agua, el consumo de combustibles fósiles y el uso de electricidad, se desarrollaron indicadores clave de rendimiento para evaluar la eficiencia y el impacto medioambiental. Los resultados revelaron disparidades en la eficiencia energética: el bloque 43-ITT fue el más eficiente, con 7,82 kWh por barril, mientras que el bloque 57-LB fue el menos eficiente, con 31,41 kWh por barril. El estudio subraya que los campos petrolíferos en maduración requieren más energía y emiten más gases de efecto invernadero, lo que subraya la necesidad de prácticas energéticas sostenibles. Las iniciativas de EP Petroecuador, como la sustitución de combustibles y la integración de electricidad renovable, permitieron reducir aproximadamente 540 kToneladas de emisiones de CO2 al sustituir 163,32 millones de galones de gasóleo por combustibles bajos en carbono y electricidad renovable. Estos resultados sirven de referencia para optimizar el uso de la energía y reducir las emisiones, y ofrecen información valiosa para que los responsables políticos y los líderes del sector adopten estrategias basadas en datos que mejoren la eficiencia energética y minimicen el impacto ambiental en el sector petrolero ecuatoriano.

Palabras claves: Consumo de energía, industria petrolera, generación de energía, indicadores energéticos, emisiones de dióxido de carbono.

RESUMO

O estudo avalia o desempenho energético e ambiental das instalações petrolíferas a montante do Equador entre 2015 e 2020, centrando-se nos principais blocos de extração. Através da análise de dados sobre a produção de petróleo, gás e água, o consumo de combustíveis fósseis e a utilização de eletricidade, foram desenvolvidos indicadores-chave de desempenho para avaliar a eficiência e o impacto ambiental. Os resultados revelaram disparidades na eficiência energética, sendo o Bloco 43-ITT o mais eficiente, com 7,82 kWh por barril, enquanto o Bloco 57-LB foi o menos eficiente, com 31,41 kWh por barril. O estudo salienta que os campos petrolíferos em fase de maturação requerem mais energia e emitem mais gases com efeito de estufa, sublinhando a necessidade de práticas energéticas sustentáveis. As iniciativas da EP Petroecuador, tais como a substituição de combustíveis e a integração de eletricidade renovável, levaram a uma redução de aproximadamente 540 kTons de emissões de CO2 através da substituição de 163,32 milhões de galões de gasóleo por combustíveis com baixo teor de carbono e eletricidade renovável. Estas conclusões servem de base para otimizar a utilização de energia e reduzir as emissões, e fornecem informações valiosas aos decisores políticos e líderes da indústria para adoptarem estratégias baseadas em dados que melhorem a eficiência energética e minimizem os impactos ambientais no sector petrolífero do Equador.

Palavras-chave: consumo de energia, indústria petrolífera, produção de eletricidade, indicadores energéticos, emissões de dióxido de carbono.

INTRODUCTION

Since the beginning of the industrial era, the necessity to achieve social welfare and economic growth generated an imperative quest for energy and non-renewable natural resources. The gross domestic product (GDP) and energy consumption increased 77.10 and 29.33 times, between 1900 and 2020, respectively, according to World Bank [1]. Petroleum has historically been the largest major energy source for total annual global energy consumption (29.09%), over carbon (26.44%), and natural gas (23.61%) [2], in 2019. The petroleum industry is one of key pillars of the global energy system, industrialization and a driver of economic, productive and social development [3] [4]. Due to the intensive quantity of energy used because the extraction, transportation, refining, and conversion of oil all involve high energy consumption and must be done continuously.

Within this framework, the energy-intensive procedures used to extract gas and oil, known as hydraulic fracturing, are also included. To refine them into products like gasoline, diesel, polymers, fertilizers, asphalt, and other derivatives, distillation, cracking, and catalytic reforming require high temperatures. Refining oil requires a substantial level of energy consumption. Distillation columns are thought to be responsible for 40% of the energy required in continuous chemical operations and refining plants. The more complete measure of efficiency known as energy efficiency can be as low as 14% for single-stage units and as high as 31.5% for two-stage units [5]. Hydrocarbons are converted into chemicals and materials through physical and chemical processes that require energy. Energy is needed to run trucks, ships, and pipelines as well as a substantial logistics infrastructure to get crude oil from extraction sites to refineries and ultimately to customers [6], and to provide more than 50% of global fuel consumption, and are expected to remain by 2035, so several studies formulate reduction strategies and improve the sustainability of the oil and gas industry [7] around the world.

The world's oil reserves differ greatly between nations and geographical areas. With an estimated 309 billion barrels of oil reserves, Venezuela is the nation with the most. Next with 266,005 million barrels is Saudi Arabia, followed by Canada with 169,000 million barrels. There are just two Latin American nations on the list: Brazil and Argentina, both of which produce 12.007 million barrels year, far less than the other [8]. The greatest reserves are in Latin America and the Caribbean [9], so some countries, such as Ecuador regarded its extraction, refining and sale, as a strategic economic resource since the 1970s, to acquire productive development, industrialization, and power generation.

In 1967, first oil exploration well named Lago Agrio – 1 was drilled to 10171 feet depth with oil production of 2.610 barrels of crude oil per day [10]. In June 1972, the Ecuadorian State Petroleum Corporation (CEPE) was created under the Hydrocarbon Law, where State assumed exploration, transformation and commercialization of crude oil, and Ecuador accomplished the status of oil exporter. CEPE, in charge of upstream, midstream and downstream infrastructure, discovered more oil fields (Lago Agrio, Aguarico and Auca), and inaugurated Trans-Ecuadorian Oil Pipeline System (SOTE) [11] to transport 250000 bpd of 30º API crude oil (27434 bpd), from Lago Agro Station 1 to Balao Station N. 11 (length: 497.7 km). Since then, the nation has focused its efforts on exploring the Amazon by obtaining a concession of over 3,000,000 hectares along in Amazon rainforest; so, several oil fields were discovered, such as, Pungarayacu and Libertador (Shushuqui, Pacayacu, Shuara and Secoya); oil production ascended to 72739 bpd [10], in 1980.

Due to larger oil production during 80s and 90s, SOTE was upgraded to 300000 bpd in 1985, 325000 bpd in 1992, and 360000 bpd in 1999 (extraction: 87738 bpd) for 28.5º API crude oil. In 2003, Ecuador implemented a new Heavy Oil Pipeline (OCP) to transport 23.71º API crude oil with a capacity of 450000 bdp [12]. According to National Oil Company (EP Petroecuador created in 1989), annual energy consumption for pumping the oil is 730693 barrels of crude oil [12], equivalent to 1.24 GWh per year.

Between mid-2014 and early 2016, the global economy faced one of the largest oil price declines since World War II, 70% price drop was caused by a boom and fast efficiency gains in United States shale oil production, the inability of OPEC to regulate global oil supply and softening demand prospects [13]. Moreover, in 2014 in Ecuador, oil extraction achieved its peak at 203 MMbbl to decrease at 198 MMbbl in 2015 [14]. Economically crucial petroleum production was caught in an irreversible downward trend, so Ecuador suffered a sharp reduction in government revenues and led to diminished public spend, with an increased emphasis on energy subsidy reforms [13] [15]. In consequence, in October 2015, Government removed industrial fossil fuel subsidies, according to Executive Order 799; industrial subsidies included diesel and fuel oil #6 for upstream oil power generation.

In order to face higher diesel prices for power generation, EP Petroecuador implemented energy efficiency projects: “*Monetizing Stranded Associated Gas*” [16], “*Optimization, power generation, and energy efficiency – NAMA-OGE&EE*” [17] aiming a general optimization of energy resources such as, replacement of diesel to formation or residual gas (previous 2015 was burned off in flares) for power generation, reduction of diesel in reciprocating engines and utilization of hydropower electricity from national grid (SNI) [18] to supply demand of some most energy consuming oil fields. Oil and gas industry is one of the most energy-intensive industries in Ecuador, including upstream (exploration, production), midstream (transportation, storage), and downstream (refining). According to the Agency of Energy and non-renewable Regulation of Ecuador, between 2015 to 2020, the most producing oil blocks extracted 636 MMbbl [19], using 5.48 TWh (23.35% Crude oil, 62.97% diesel, 13.69% gas) [20]; so, carbon dioxide emissions associated with oil production is 3.88 million of metric tons of CO_2 equivalent [21] during power generation.

As mentioned before, 62.97% of total power generation came from diesel, and regarding rise of price of industrial diesel, so most energy efficiency projects focused on this type of electricity generation. Typically, diesel generators run at about 40% efficiency in its optimum operating range, high-temperature greenhouse gases are 490 ºC, fuel consumption (at 75% of load capacity) is 81.7 gallons per hour, exhaust flow rate 2.97 kg/s, and heat rejection to exhaust 1690 thermal kW [22]. Thereby, the Instituto de Investigación Geológico y Energético – IIGE, based on previous research projects, such as, "*Estudio de incremento de eficiencia energética en plantas termoeléctricas - Study of increasing of energy efficiency in thermoelectric generation power plants*" [23], generated additional electricity using cero fossil fuels, throughout a waste to energy Organic Rankine Cycle [24] power generation plant connected to exhaust gases chimney at 350 ºC and 3.2 kilograms per second, from a diesel generator (HYUNDAI 9H21/32 – 1.7 MW) at 80% of working factor. The ORC evaporator device (shell and tube heat exchanger) utilized flue gases as fuel to rise temperature of an organic heat transfer fluid (NOVEC 649) up to 150 ºC at 10 barg, to produce up to 200 kWe inside a screw expander [25].

Furthermore, EP Petroecuador, under a specific agreement among Ministerio de Hidrocarburos, The Banco Interamericano de Desarrollo - BID, Petroamazonas EP, and IIGE, developed a consultancy named "*Apoyo a la gestión de la eficiencia energética en el Sector Hidrocarburos - Support for energy efficiency management in the Hydrocarbons Sector*"[26], whose general objective was focused on the comprehensive diagnosis of energy situation, maturity of major oil-producing blocks, and energy efficiency techniques, in upstream hydrocarbon sector in Ecuador.

In order to address the technical issues mentioned earlier, IIGE, with the support of EP Petroecuador and the Ecuadorian Government, carried out a project titled "*Study of waste to energy recovery systems in upstream oil facilities*."[27], The project's initial phase involved establishing energy efficiency indicators [28], such as energy consumption, CO2 emissions per unit of oil production, and energy mix by fossil fuel sources. The overarching goal was to quantify the recovery of heat from exhaust gases in power generation, with the potential to convert it into electricity, heat, or a combination of both [29]. The development and selection of performance indicators represent the first step in analyzing the current energy situation and drawing initial conclusions about past trends and future evolution. This process could help answer the research question: "What are the key energy and environmental performance indicators at upstream oil facilities in Ecuador, and how do they influence operational efficiency and environmental impact?

This makes it possible to adopt a broader and concentrated approach across all supply chain levels, which improves understanding of the steps that could be taken to improve sustainability performance [30]. All data acquired from analysis equipment will provide useful information to determine the global energy situation, optimization of diesel and gas generators, and reduction of operational costs, among other benefits [31], [32].

METHODOLOGY

All data were provided by EP Petroecuador from six major oil-producing blocks: 57-Shushufindi (13.95%), 57-Libertador (2.94%), 58-Cuyabeno (4.43%), 60-Sacha (13.13%), 61-Auca (13.22%), and 43-ITT (7.64%), covering a 5-year period, and 55.3% of oil production in Ecuador from 2015 to 2020. Data were cross-checked with oil production data supplied by the by Agencia de Regulación y Control de Energía y Recursos Naturales No Renovables (ARCERNNR) to ensure accuracy and consistency.

The descriptive statistical analysis, including mean, standard deviation, and percentiles, was used to calculate energy and environmental performance indicators. The analysis was conducted using Excel, and a significance level of 0.05 was employed for hypothesis testing. Table 1 displays the sample, which consists of the six major oil-producing blocks in Ecuador, and Figure 1 shows their geographical locations:

Table 1:

Table 1. Crude oil blocks.

Item	Official Name	Abbreviation name
1	43-ITT (Ishpingo, Tambococha, Tiputi)	43-ITT
2	57-Shushufindi	57-SH
3	57-Libertador	57-LB
4	58-Cuyabeno	58-CYB
5	60-Sacha	60-SA
6	61-Auca	61-AU

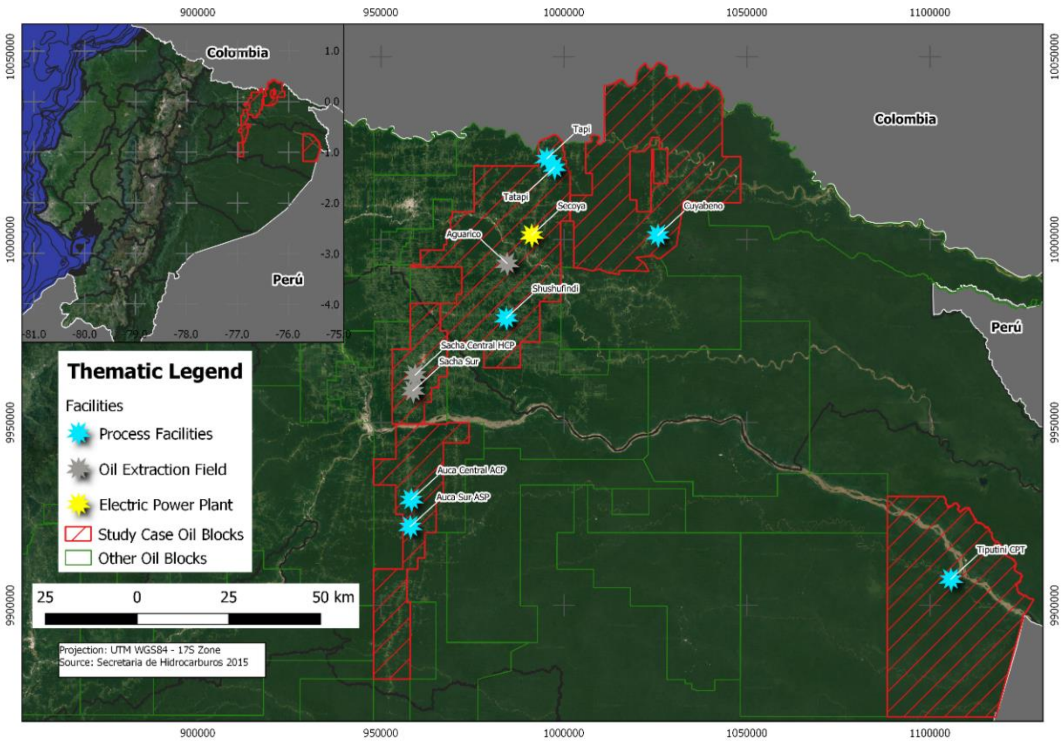

Figure 1. Geographical location of major oil-producing block in Ecuador.

After selecting the sample, IIGE requested EP Petroecuador, under a specific agreement, to provide information about the research variables. These include production (oil [barrels/month], raw water [barrels/month], and gas [cubic feet x 1000/month]), fossil fuel consumption (crude oil [barrels/month], diesel [gallons/month], and gas [cubic feet x 1000/month]), power generation by fossil fuel (crude oil, diesel, and gas) [kWh/month], electricity imported from SNI [kWh/month], and costs associated with power generation [USD/kWh] [19], from 2015 to 2020. All data is collected periodically using direct measurement.

Energy indicators are regarded as a significant tool for analyzing interactions among economic, energy consumption and carbon dioxide emissions [28]. So, energy indicators tabulated are:

- Relations of oil, raw water and gas extraction. This indicator shows annual evolution of raw water-oil, and gas-oil, in prioritize oil blocks, to determine maturity of oil fields [33].

$$Rel_{w/o} = \frac{Barrels\ of\ Raw\ water}{Barrels\ of\ crude\ oil} \quad (1)$$

$$Rel_{g/o} = \frac{Cubic\ feet\ of\ gas\ \ x\ 1000}{Barrels\ of\ crude\ oil} \quad (2)$$

- Energy consumption per unity of production. This indicator shows the total energy consumption (mix of fossil fuels from: oil, diesel, gas, and imported electricity from SNI), per barrel of crude oil.

$$ECUP = \frac{Total\ energy\ consumption\ [kWh]}{Crude\ oil\ [barrels]} \quad (3)$$

- CO_2 emissions per unit of production. This indicator shows carbon dioxide emissions [21] produced by power generation (kWh/year), per barrel of crude oil.

$$CDE = \frac{4.33e{-}4\left[\frac{Tons\ CO_2}{kWh}\right]\ \text{x pg}\left[\frac{kWh}{year}\right]}{Crude\ oil\ [barrels]} \quad (4)$$

RESULTS

From 2015 to 2020, the six most productive blocks, were extracted 636.15 million barrels of 1.150 million barrels of Ecuadorian total production [34]. The most productive oil blocks were 57-SH, 61-AU and 60-SCH (160.44, 152.05 and 151.05 million of barrels of crude oil, respectively).

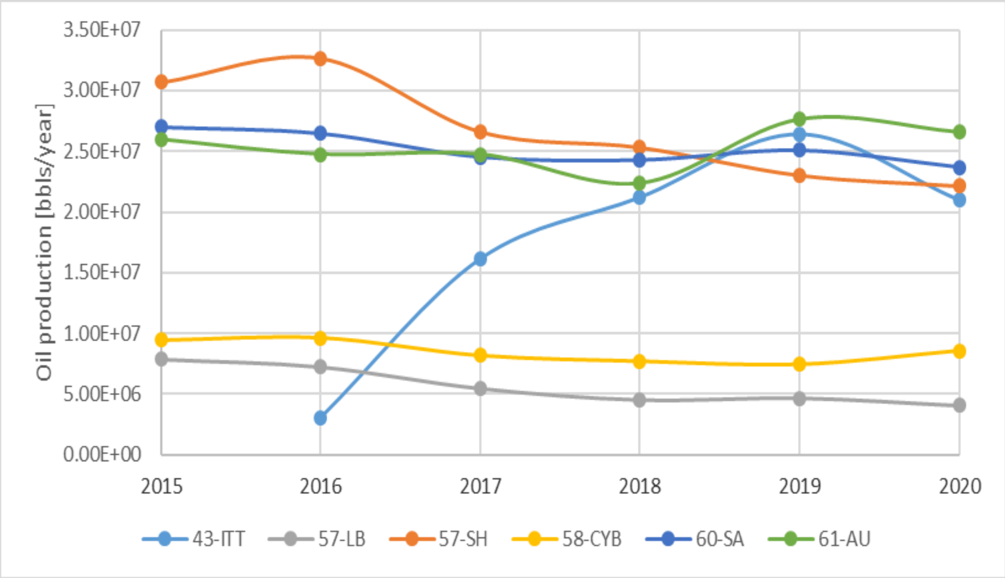

Figure 2. Oil production 2015-2020.

Crude oil production reached its peak in 2014 with a daily extraction of 543000 barrels [14]. From the present analysis, five of six oil blocks reached their peak and started to decrease production gradually (-4.18 % annually on average). The exception is 43-ITT, which was exploded initially in 2016 by EP Petroecuador. Its production increased by 586.46%, from 3.05 in 2016 to 20.99 million barrels in 2020, contributing 7.64% of total national production [34]. Nevertheless, despite the fact of a big production of crude oil, also, there was a large production of raw water, due to the geographical location and nature of the field [35]. *Figure 3* shows the evolution of the ratio between raw water and crude oil production; this ratio is the first step to elucidate the maturity of an oil field [36].

The continuous exploitation of some fields increased the production of raw water, because the production stream in the majority of mature oil reservoirs is mostly made up of water with a minimal volumetric oil proportion [37]. For example, according to *Figure 3* in block 57-LB, the extraction of raw water was 3.75 in 2015, and rise to 9.64 in 2020, per oil barrel (*Figure 3*). The blocks with the highest raw water production are 57-LB, 43-ITT and 58-CYB, with an average of 6.78, 4.51 and 4.23 water barrels per oil barrel, respectively.

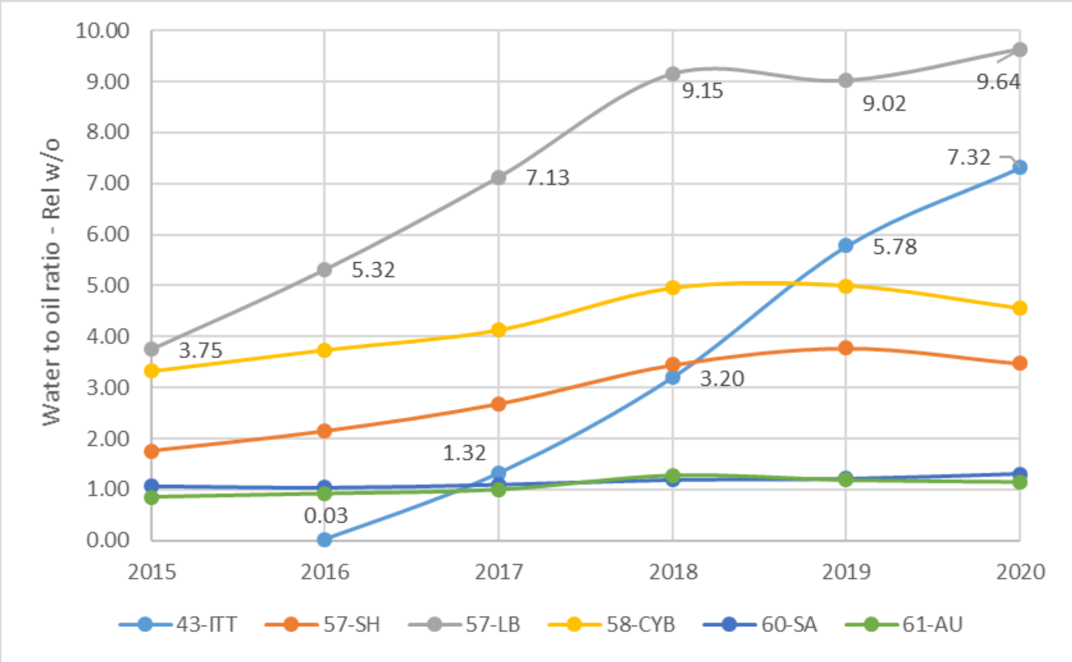

Figure 3. Evolution of raw water vs crude oil ratio - 2015-2020.

In addition, another indicator of maturity is the increase of gas production [33]. *Figure 4* shows the evolution of petroleum gas vs crude oil ratio. In minor gas blocks, such as, 43-ITT, 58-CYB, 60-SA, and 61-AU, the average gas extraction is 121.82 cubic feet per oil barrel; on the other hand, 57-SH and 57-LB are the blocks with the highest proportion of gas production, with 360.30 and 652.35 cubic feet per oil barrel, respectively.

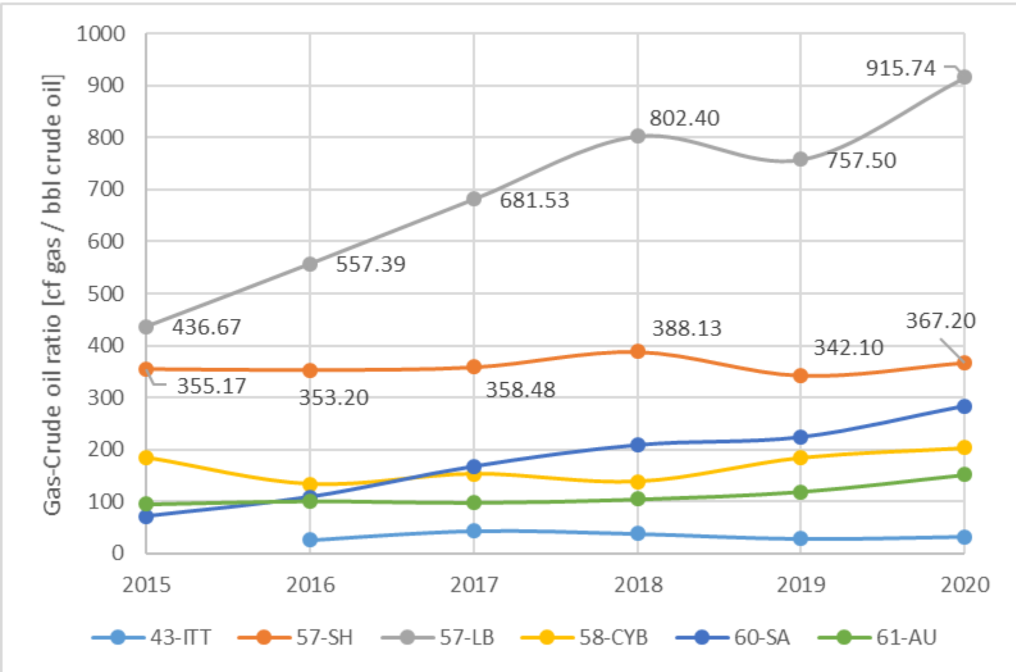

Figure 4. Gas production vs crude oil ratio – 2015-2020

By the time oil fields become depleted, more energy [38] is required for power generation for flow assistance during extraction process, pressure support pumps, raw water separation from oil, mechanical equipment such compressors, gas flaring, venting, pipeline transport, among others [39]. *Figure 5*, shows the evolution of energy consumption per unity of production of crude oil (ECUP). The block 57-LB is the most energy consuming block field (32.04 kWh/bbl), to produce 5.63 million barrels of crude oil from 2015 to 2020 in 57-LB, energy required was 984.90 GWh, using 123.73 kbbl of oil, 2.94 million gallons of diesel and 2597.41 MCF of gas [19].

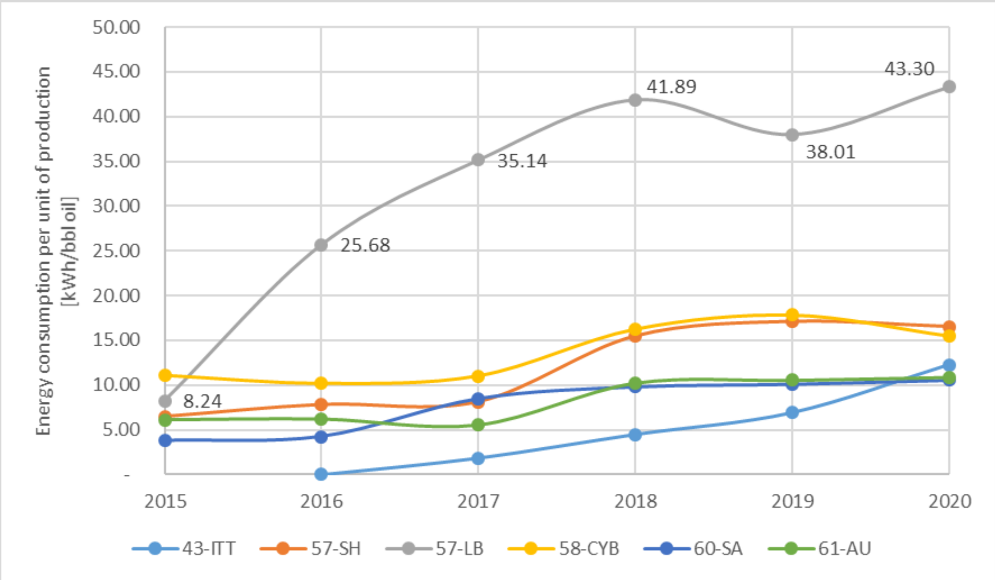

Figure 5. Energy consumption per unit of production – 2015-2020.

In contrast to 57-LB, in the other blocks, the average ECUP is 9.90 kWh/bbl, due to the electric interconnection from SNI to exclusive electric oil grid [18]. Electricity received from 2017 to 2020 was 1196.05 GWh: 57-SH (856.24 GWh), 60-SA (123.68 GWh) and 61-AU (216.11 GWh). Despite the fact 57-LB received energy from SNI (51.79 GWh) since 2017 to 2020, reduced diesel consumption (3.08 million gallons 2017-2020), and increased gas generation (18.55% between 2015 to 2020), ECUP has continued growing from 8.24 to 43.30 kWh/bbl, from 2015 to 2020. The best-case example is Block 57-LB, which has the lowest oil extraction rate (2.94% of total production, equivalent to 33.83 million barrels from 2015 to 2020). However, it stands out as the top raw water producer, generating 9.64 barrels of raw water per barrel of oil, and as the leading gas formation generator, producing 915.75 cubic feet of gas per barrel of oil. This represents 2.5 times more gas extraction compared to the second-highest gas-producing Block 57-SH (367.20 cubic feet of gas per barrel of oil).

Excessive raw water and gas production is a complex issue for mature fields [36], such as blocks, 57- Libertador and 58-Cuyabeno, and imply a serious economic and environmental impact. Moreover, other symptoms of maturity are aging of equipment, more energy consumption due to decreasing reservoir pressure [33], and in consequence, more carbon dioxide emissions per unit of production, as it shows in *Figure 6*.

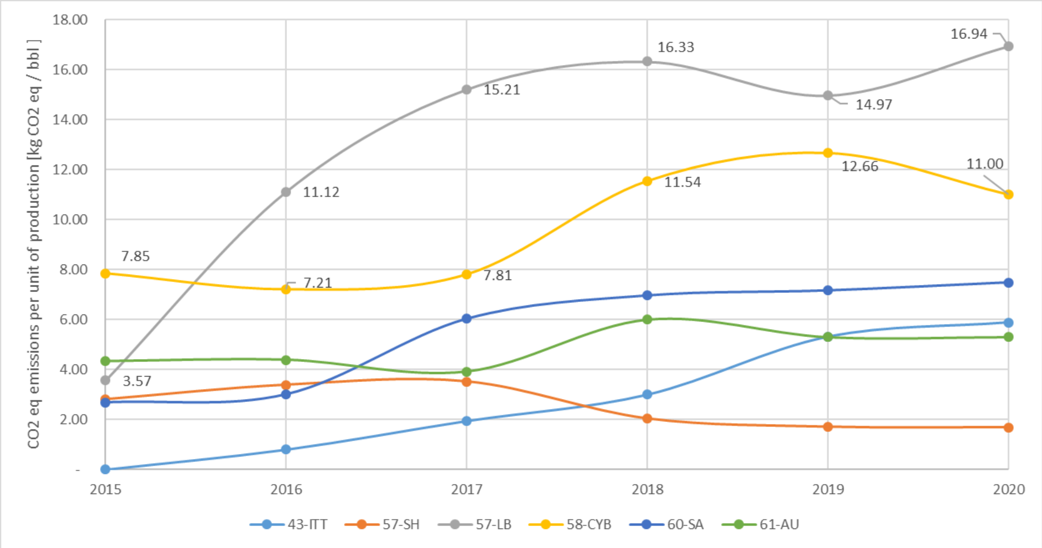

Figure 6. Carbon dioxide equivalent emissions per unit of production.

To diminish carbon emissions, EP Petroecuador implemented smart energy efficiency actions, such as, utilization hydropower electricity imported from SNI [18]. The 500/230 kV, 450 MVA electricity national grid were interconnected to oil electricity mainstream system (230/138kV, 300 MVA), to feed energy (due to the near geographical location) to 57-SH and 61-AU [40]. Since 2017, 57-SH block consumed 856.24 GWh from SNI, which replaced 4.82 million gallons of diesel and 649.56 millions of cubic feet of gas, so 41.70 kTon of CO_{2eq} are the avoided emissions [21]; on the other hand, 61-AU block consumed 216.11 GWh from SNI, replacing 25.94 kbbl of crude oil as fuel in electricity generation equipment, from 2017 to 2018; the avoided emissions were 12.18 kTon of CO_{2eq}.

EP Petroecuador continues pursuing efforts to limit to 1.5 ºC the rise of global temperatures [41], aligned with the Paris agreement; this requires widespread changes across all parts of oil industry. The *Table 2* summarizes future energy efficiency actions to keep diminishing energy consumption per unit of production in oil fields:

Table 2. Energy efficiency actions 2024-2030

Item	Block	EP Petroecuador Energy efficiency actions 2024-2030 [42]
1	57-SH	• Implementation of gas turbine TM2500 14 MW • Expansion of electricity interconnection system 69 kV to Shushufindi Sur and Aguarico oil fields. • Expansion of electricity mainstream interconnection system to 138 kW. • Utilization and transport of formation gas from Drago field to Shushufindi Refinery gas facility.
2	57-LB	• Improvement of gas power generation up to 4 MW.

		• Expansion of electricity interconnection system to 13.8 kV – Tapi-Tetete-Frontera. • Improvement of gas-oil power generation Secoya.
3	58-CYB	• Design of electric grid – Shushufindi-Tarapoa-Cuyabeno 30 MW • Optimization of oil treatment system. • Relocation and expansion of gas generation (3 MW) including gas compression system boost. • Implementation of new control and monitoring system.
4	60-SA	• Repowering Sacha Central power generation plant up to 4 MW. • Expansion of electricity mainstream interconnection system to 138 kW. • Utilization higher capacity (0.5 to 1 million standard cubic feet of gas per day) compressors for formation gas. • Utilization and transport of formation gas from Sacha Sur and Sacha Central to Shushufindi Refinery gas facility.
5	61-AU	• Expansion of electricity interconnection system from 35 to 69 kV. • Improvement of gas power generation up to 9 MW. • Improvement of crude oil power generation up to 18 MW. • Repowering 28 crude power stations.

All energy efficiency actions to be implemented by EP Petroecuador, mentioned in *Table 2*, conform as an integral item of energy and environmental auditing, due to its ability to diagnose opportunities to enhance strategies, such as, processes optimization, acquisition of new rotating equipment, heat exchangers and gas-fired equipment according to API 611, and correction of heat losses and leaks [41].

CONCLUSIONS

In Ecuador from 2015 to 2020, the crude oil production were 1150.28 million barrels in the six major oil extraction blocks: (43-ITT, 57-SH, 57-LB, 58-CYB, 60-SA and 61-AU), using 5482.21 GWh from fossil fuels and hydropower electricity (oil 20.25%, diesel 55.80%, gas 9.46% and SNI 14.49%, in average), and producing 3231 thousand tons of carbon dioxide equivalent. Nevertheless, due to the first energy efficiency action taken by EP Petroecuador, the replacement of diesel for generation (163.32 million of gallons) by low-carbon fuels [43], such as, residual gas (7709 million cubic feet) and renewable electricity from SNI (1247.85 GWh), the replacement of diesel with low-carbon fuels (gas) and renewable electricity resulted in avoiding approximately 540kTons of CO2 equivalent emissions. This aligns with findings in global literature that emphasize the significant role of fuel substitution and the integration of renewable energy in reducing the carbon footprint of oil production operations [44].

The production of crude oil has been on the decline [38], as depicted in *Figure 2*. This shift has resulted in an increased requirement for energy in various critical processes associated with oil extraction, such as power generation for flow assistance, pressure support pumps, water-oil separation, and operation of mechanical equipment like compressors, among others [39]. The variations in energy consumption across different oil fields—ranging from 7.82 kWh/bbl in the most efficient field (43-ITT) to 31.41 kWh/bbl in the least efficient field (57-LB) are consistent with prior studies showing that energy intensity is heavily influenced by factors such as the depletion of oil fields, the geographical location of extraction sites, and the maturity of the technology in use [45]. As field depletion progresses and extraction processes become more energy-intensive, there is a critical need for continuous technological upgrades and process optimization, which can help mitigate this rise in energy demand and emissions.

Additionally, the role of renewable energy in reducing the environmental impact of oil production is well-documented in the literature [46] [47] [48]. The incorporation of renewable electricity from the SNI has led to a noticeable decrease in emissions in Ecuador's upstream oil sector. This highlights the significance of sustaining this progress and investing in renewable energy sources to counterbalance the environmental impacts of fossil fuel extraction.

This insight into energy efficiency per unit of production can be pivotal in identifying areas for improvement. Fields with higher energy consumption may benefit from targeted measures to enhance operational efficiency, potentially through technological upgrades, process optimization, or the adoption of more energy-efficient practices, due to move into more remote geographical locations [38] and field depletion, so, in consequence, more energy is required for power generation for flow assistance during extraction process, pressure support pumps, raw water separation from oil, mechanical equipment such compressors, gas flaring, venting, pipeline transport, among others. As it shows in *Figure 5*, the energy consumption per unit of production is linked to the energy efficiency; the less energy used per extracted oil barrel, the more efficient the field: 43-ITT: 7.82, 60-SA: 7.84, 61-AU: 8.25, 57-SH: 11.91, 58-CYB: 13.65 and 57-LB: 31.41 kWh/bbl.

In conclusion, the study emphasizes the importance of making strategic energy decisions in the oil and gas industry in Ecuador. It presents empirical evidence that transitioning to low-carbon fuels and renewable energy sources, along with implementing efficiency measures specific to each field, can significantly reduce emissions. However, continuous investments in energy-efficient technologies and integrating renewable energy will be crucial to maintain these improvements. These findings add to the growing body of literature that supports the adoption of energy transition strategies in carbon-intensive sectors to mitigate the impacts of climate change.

FUNDING

This investigation received funding from the Technical Secretariat of Planning "SENPLADES" under grant number SENPLADES-SIP-2018-1045-0F for the project "Study of waste to energy recovery systems in upstream oil facilities", executed by Instituto de Investigación Geológico y Energético "IIGE" between 2019 to 2021. The total funding amount was USD 90,000.

CONFLICT OF INTEREST DECLARATION

The authors of this research declare that there is no conflict of interest.

CONTRIBUTION OF THE ARTICLE IN THE LINE OF RESEARCH

This article offers insights into the energy situation in the upstream oil and gas industry in Ecuador. While this topic has not been previously published, it serves as the foundation for future energy efficiency projects developed in partnership with EP Petroecuador, IIGE, and universities in Ecuador.

STATEMENT OF EACH AUTHOR'S CONTRIBUTION

[Andrés Campana - Díaz]: Project administration, Funding acquisition, Conceptualization, Methodology, Formal analysis, Writing—original draft.

[Marcelo Moya]: Data analysis, Validation, Writing—review and editing.

[Esteban Urresta]: Investigation, Data analysis, Writing—review and editing.

[Renato Harnisth]: Geographical data, data acquisition, Writing—review and editing.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to Instituto de Investigación Geológico y Energético – IIGE for their invaluable support that were crucial to the successful completion of this project. Their commitment to industrial energy efficiency and their continuous encouragement have been instrumental in achieving our research objectives.

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