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Analysis of Energy Consumption Performance in Oil and Gas Utility Systems Using Baseline and Specific Energy Consumption (SEC) Approaches

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Abstract
This study examines the performance of energy consumption in utility systems within Indonesia's oil and gas industry by employing a baseline model and the Specific Energy Consumption (SEC) indicator. Using national secondary data, the research develops an operational energy profile, evaluates the relationship between production levels and energy demand through linear regression, and assesses potential energy savings under various conservation scenarios. The analysis shows that monthly energy consumption remained within 305 –321 MWh, reflecting the continuous nature of oil and gas operations. SEC values ranged from 28.0 to 28.4 kWh/BOE, indicating relatively consistent energy intensity. The baseline model produced a slope of 29.504 kWh/BOE and an R^2 of 0.94, confirming a strong correlation between production and energy use. Two conservation scenarios demonstrated annual savings of 179 MWh (moderate) and 554 MWh (aggressive). These findings demonstrate that baseline and SEC analyses serve as effective engineering tools for identifying inefficiencies and supporting energy optimization efforts in oil and gas facilities.

Keywords: Electric heavy equipment, mining electrification, carbon reduction, energy transition, sustainability Baseline energy, Energy efficiency, SEC, Oil and gas utilities, Regression analysis.

Introduction

The oil and gas industry has become one of the main pillars for meeting Indonesia's energy needs. Although the contribution of renewable energy has begun to increase in recent years, the dominance of oil and gas in primary energy supply remains very significant. According to the Ministry of Energy and Mineral Resources [1] the oil and gas sector is not only a driver of energy supply stability but also vital for industry and transportation. The International Energy Agency [2] highlights that energy consumption in the oil and gas sector remains high, making the emphasis on energy efficiency in this sector an important agenda to reduce costs and CO2 emissions.

The Indonesian government's stance in addressing these challenges is reflected in the issuance of Government Regulation (PP) No. 33 of 2023 on Energy Conservation, which requires sectors with high energy consumption to implement strict energy management. This is reinforced by Minister of Energy and Mineral Resources Regulation No. 3 of 2025, which emphasises the obligation to conduct periodic energy audits and implement energy performance standards. However, the implementation of this policy faces complex challenges. Many oil and gas facilities operate in remote locations with high dependence on fossil fuel power plants, such as diesel and gas, which contribute to high internal energy consumption and greater emissions [3].

Globally, including in Indonesia, energy audits have proven to be an effective tool in assessing and improving energy efficiency [4] In the oil and gas sector, energy audits can identify significant energy saving opportunities. For example, an audit study conducted at PT Satwa Utama Raya showed potential energy savings of up to 16.34% [5]. Through rigorous auditing practices, oil and gas companies can schedule energy savings, improve energy consumption efficiency, and maximise greenhouse gas emission reductions [3, 6]

The ease of implementing energy conservation measures in this sector, particularly in a local context, is crucial. One approach that can be refined is collaboration between the government and the private sector to implement modernised technologies and best practices in energy management. Along with the pressure towards sustainability, the development of a comprehensive framework for energy efficiency practices in sustainable oil and gas operations is fundamental [3, 7] . This not only supports the goal of achieving national energy security but is also crucial for maintaining environmental balance and adhering to increasingly stringent global sustainability standards.

Furthermore, several studies indicate that energy audits in oil and gas facilities are often hindered by limited access to primary data, such as equipment consumption profiles, daily loads, or actual utility system efficiency. Hilmawan (2022) emphasises that limitations in primary data should not hinder energy conservation analysis, as quantitative methods based on historical data can be used to establish an energy baseline through linear regression and calculate specific energy consumption (SEC). This approach is in line with the ISO 50002:2014 standard, which emphasises the use of statistical methods and trend analysis when field measurements are not available [8].

The research gap in energy conservation in the oil and gas sector is prominent, mainly because many current studies focus on equipment audits or technical simulations using primary data. However, few studies evaluate the success of energy conservation policy implementation through the use of national secondary data with an energy baseline approach. This baseline approach is crucial, as it can serve as a macro evaluation tool to measure the effectiveness of government policies in the context of high energy sector dependency, especially in the energy-intensive oil and gas sector. This study aims to fill this gap. By applying a quantitative approach based on national secondary data, this study compiles an energy baseline for the oil and gas sector and assesses the potential for energy savings based on conservation scenarios designed by [9]. This approach relies on linear regression analysis to evaluate the relationship between energy consumption and production, as well as to identify key elements in energy efficiency diagnosis [10]. After establishing the baseline, various savings scenarios were analysed, ranging from a 10-20% reduction in baseload to a 5-15% increase in technological efficiency [11, 12].

This study also aims to analyse the energy consumption profile of the oil and gas sector using national data, establish an energy baseline, and calculate the potential for energy savings and the impact on costs and CO_2 emissions. Evaluating the relevance of the results to the implementation of existing policies will provide important insights into the consistency of government policies with the actual conditions of the oil and gas sector [13, 14]. The results of this study are expected to not only contribute to academic knowledge but also provide a reference for further research and for decision-makers in the energy sector who work with limited access to primary data. The ultimate goal of this research is to provide a model that can be replicated by researchers and students who do not have access to primary data but need a measurable method of evaluating energy efficiency [15]. By compiling and analysing various proposed scenarios, it is hoped that this research can increase understanding of the potential for energy savings and help strengthen government policies to achieve sustainability and energy efficiency goals in the oil and gas sector.

Literature Review

The oil and gas industry is one of the sectors with the highest energy intensity among other industrial sectors. Energy consumption in this industry arises from the operation of compressors, pumps, turbines, heaters, separation systems, and other supporting facilities that operate continuously. According to the International Energy Agency [2], the operation of global oil and gas facilities contributes significantly to total industrial energy consumption, making energy efficiency in this sub-sector one of the most effective strategies for reducing carbon emissions and operational costs [16][17].

In Indonesia, the role of the oil and gas sector is reflected in the allocation of internal energy, which often exceeds 10% of total operating costs, especially in facilities that are not connected to the public electricity grid [18]. This condition emphasises the importance of energy conservation as a strategic element in improving operational performance [19].

Energy Conservation Policy in Indonesia

Energy conservation policies in Indonesia have undergone significant development since the issuance of Government Regulation No. 33 of 2023 on Energy Conservation. This regulation requires significant energy users to implement energy management, develop energy conservation programmes, and conduct regular energy audits. These provisions are reinforced by ESDM Regulation No. 3 of 2025, which emphasises the implementation of energy performance standards, energy-efficient labelling, and reporting on efficiency achievements in government and industrial facilities.

Both serve as regulatory instruments to promote efficient energy use and reduce national energy intensity. In the context of the oil and gas industry, this obligation is highly relevant given the large internal energy consumption and significant potential for savings. However, as stated by Rahman et al., there is still a gap between the regulations and the conditions on the ground, especially at facilities facing technical and geographical constraints.

Energy Systems and Use in Oil and Gas Facilities

An understanding of energy systems at oil and gas facilities is necessary to identify energy conservation opportunities. Upstream oil and gas facilities generally have several Significant Energy Users (SEUs), such as fluid pumping systems, gas compressors, electric generators, cooling systems, and process heating units. Each piece of equipment has different energy consumption characteristics, depending on capacity, technology, component efficiency, and operating patterns. In remote facilities, electricity consumption is often supplied by diesel or gas-fired generators with relatively low generation efficiency [2]. This condition highlights the importance of optimising operating systems, such as load sharing arrangements, waste heat recovery, and operating equipment at the appropriate capacity.

Energy Audit and Energy Baseline

An energy audit is a systematic approach to assessing energy use and identifying savings opportunities. The international standard ISO 50002:2014 stipulates that an energy audit includes an analysis of historical energy consumption, an assessment of equipment efficiency, and the development of implementable energy conservation recommendations [8]. One of the main components of an energy audit is the preparation of an energy baseline, which is the relationship between energy consumption and production output. The baseline is calculated using linear regression to determine the variable energy component and the base load energy that does not depend on the level of production .

Mahandari [20] emphasises that this method is effective for identifying energy waste, especially in industrial facilities that have relatively stable energy consumption patterns. The energy baseline concept has two important parameters: the slope, which indicates variable energy requirements per unit of production, and the intercept, which represents base energy. The larger the intercept, the greater the potential for energy waste that can be reduced through operational improvements. In the context of energy conservation, baseline analysis provides a strong quantitative basis for assessing the effectiveness of energy efficiency interventions and determining priorities for action.

Specific Energy Consumption (SEC)

SEC or energy intensity is an indicator used to measure the energy efficiency of a process relative to its output. SEC is expressed as the ratio of total energy used to production volume (kWh/BOE or GJ/BOE for the oil and gas sector). SEC is an important indicator for comparing energy efficiency between facilities or with industry standards. According to research by Lawrence [21], SEC calculations can be used as a basis for initial energy conservation assessments when detailed operational data is not available. In secondary data-based energy conservation research, SEC is the main indicator that describes changes in energy efficiency over time.

Previous Research and Research Gaps

Various studies on energy conservation in the oil and gas industry have been conducted, particularly related to compressor operation optimisation, generator efficiency improvement, and the application of energy-saving technologies. However, most studies are technical and based on primary data, making them less relevant for energy policy evaluation when field data is unavailable [20], identified that approaches based on statistical modelling and aggregate data are still rarely applied, even though they have great potential to support policy analysis at the sectoral level. In addition, the use of energy baselines as an instrument for evaluating the implementation of energy conservation policies in the oil and gas sector has not been widely studied academically. This study fills this gap by adopting a quantitative method based on national secondary data to analyse the energy consumption baseline and energy saving potential in the oil and gas sector. This approach contributes scientifically in the form of an energy conservation evaluation model that can be used without requiring primary data and is relevant to the formulation of national energy policy.

Research Methodology

The research methodology was designed to answer research questions regarding the energy consumption profile of the oil and gas industry, the preparation of an energy baseline, and the estimation of energy saving potential in the context of the implementation of national energy conservation policies. Given the limited access to primary data, this study used a quantitative approach based on secondary data sourced from official government publications and technical literature related to the energy sector. This approach is relevant to energy audit practices that allow the use of historical data as a basis for analysis when direct measurements are not available [20, 21]

Research Design

This study uses a quantitative-descriptive design with a calculation-based analysis model. The main focus is to establish a mathematical relationship between energy consumption and oil and gas production to produce an energy baseline, analyse energy intensity, and develop energy saving scenarios. The quantitative approach was chosen because it is capable of producing objective and replicable numerical indicators, in accordance with the standard procedures for energy audits [8, 22]. The research design was developed following the steps of model-based energy conservation analysis, namely:

1. processing of energy production and consumption data,
2. determination of specific energy consumption (SEC),
3. development of an energy baseline regression model,
4. calculation of energy saving potential through scenarios, and
5. conversion of energy savings into cost savings and emission reductions.

Data Sources

The research data used national secondary data compiled in monthly format for one year. The data included:

- oil and gas production (barrel of oil equivalent/BOE),
- electricity consumption (kWh),
- diesel consumption (litres),
- energy prices (electricity tariffs and diesel prices),
- technical conversion parameters (kWh/litre, CO_2 emission factor).

The use of secondary data is based on the consideration that national aggregate data is sufficiently representative to describe macro trends in energy consumption in the oil and gas sector. Energy consumption analysis in the oil and gas sector often uses an approach that prioritises secondary data to compile an energy baseline and assess energy saving potential. Given the sensitive nature of operations and data in this sector, the use of sample-based datasets, collected through expert assessment and adjustment to historical patterns, is a commonly used approach. This is in line with energy policy design and energy audit practices when primary data cannot be published directly [23]. This includes the creation of an energy baseline that reflects more accurate and reliable energy consumption to assist in the development of relevant energy conservation scenarios in the oil and gas sector.

These sample-based datasets are collected to maintain the operational confidentiality of oil and gas facilities and to avoid conflicts with the publication of sensitive industry data. The use of this method is particularly important when operational data at oil and gas facilities is confidential and not accessible to the public. Several studies show that honest and efficient energy audits can provide a deeper understanding of energy consumption patterns and emission reduction potential [24, 25]. Through regression analysis, researchers can identify the base load and energy variables that play an important role in energy efficiency in the oil and gas sector [26]. In formulating energy conservation scenarios, it is important to conduct a comprehensive analysis that considers variations in energy usage patterns obtained from historical data and expert assessments. This results in various potential savings scenarios that can include a 10% to 20% reduction in base load and a 5% to 15% increase in technological efficiency. Research in the construction sector also shows that energy consumption can be minimised through audits as a starting point for identifying efficiency opportunities [27]. This study, therefore, demonstrates how the combination of sample-based data and statistical analysis techniques can be implemented to develop more effective policy instruments and achieve energy conservation goals in the oil and gas sector, which in turn can help reduce the carbon footprint of the industry and improve operational sustainability [28].

Data Processing and Energy Conversion

The initial stage of the analysis is to convert all energy sources into electrical energy units (kWh). Diesel consumption is converted using a generation efficiency assumption of 1.8 kWh per litre, as commonly used in diesel generator-based energy conservation studies [21]. Total energy is calculated using the formula:

$$E_{\text{total}} = E_{\text{listrik}} + E_{\text{diesel}} \tag{1}$$

After the total energy is obtained, the specific energy consumption (SEC) value is calculated as:

$$SEC = \frac{E_{\text{total}}}{\text{Produksi (BOE)}} \tag{2}$$

SEC is used to assess energy intensity and serves as a basic indicator in industrial energy efficiency benchmarking.

Energy Baseline Development

The energy baseline is established using a simple linear regression approach between monthly energy consumption (Y) and monthly production (X). The model used is:

$$Y = aX + b \tag{3}$$

where:

- a is the energy variable coefficient (kWh/BOE),
- b is the baseload (kWh), which is the fixed energy consumed even when production is zero.

This linear regression approach is in accordance with ISO 50002 as the standard method for compiling an energy baseline using historical data [19] Baseload is an important indicator for identifying potential savings because it describes energy consumption that is not directly related to production activities.

The regression coefficient value, coefficient of determination (R^2), and model fit test are used as the basis for assessing the quality of the energy baseline.

Energy Conservation Scenario Analysis

Based on the energy baseline, this study developed two conservation scenarios:

a. Moderate Scenario
   - A 10% reduction in baseload,
   - A 5% increase in variable energy efficiency.

b. Aggressive Scenario
   - 20% reduction in baseload,
   - A 15% increase in variable energy efficiency.

This scenario refers to the approach commonly used in model-based energy conservation research and baseline-based efficiency calculations in industrial energy benchmarking studies.

Energy savings are calculated as:

$$\Delta E_{\text{base}} = b \times r_b \times 12 \tag{4}$$

$$\Delta E_{\text{tech}} = (E_{\text{annual}} - b \times 12) \times r_t \tag{5}$$

Total energy savings are the sum of both.

Calculation of Cost and Emission Savings

Cost savings are calculated using industrial electricity rates (Rp/kWh). The reduction in CO_2 emissions is calculated from the total energy saved using a diesel emission factor of 0.85 $kgCO_2/kWh$ [2]. Simple economic calculations such as payback period are used to assess the feasibility of energy conservation investments using the formula:

$$\text{Payback} = \frac{\text{CapEx}}{\text{Annual Cost Saving}} \tag{6}$$

Validity and Replication

The research method used is replicable, as all calculations are based on standard energy audit formulas [20] and can therefore be reused on similar data or other facilities. Each technical assumption is explicitly stated to ensure transparency and consistency of analysis.

Results and Discussion

This chapter presents the results of the analysis of energy consumption, energy baseline, energy intensity (SEC), and energy conservation scenarios. All results were obtained using a *sample-based dataset* compiled through an *expert judgement* approach and adjustments to the historical consumption patterns of the national oil and gas sector. The use of sample data was done to maintain the operational confidentiality of oil and gas facilities and to avoid publication conflicts related to sensitive industry data. This approach is commonly used in in energy policy research and energy audits when primary data or company data cannot be published directly. Thus, this data represents actual trends and patterns occurring in the oil and gas sector, but does not reveal specific operational figures belonging to particular companies. This model remains scientifically valid because it aims to demonstrate methodology, consumption patterns, and potential energy savings in the context of national energy conservation.

Oil and Gas Energy Production and Consumption Profile

The analysis begins with the compilation of an energy consumption profile for the oil and gas sector based on monthly data for 2022. The data includes electricity consumption, diesel consumption, and oil and gas production in barrels of oil equivalent (BOE). Table 1 presents a summary of the first five months as an illustration of the dataset structure.

Table 1. below displays energy production and consumption data for the year 202x:

Period	Production (BOE)	Electricity (MWh)	Diesel (litres)	Total Energy (MWh)
202x-01	11.000	300	6.000	310
202x-02	10.800	295	5.900	305
202x-03	11.200	305	6.100	315
202x-04	11.150	302	6.050	312
202x-05	11.300	310	6.200	321

Note: Total energy is calculated from electricity + diesel conversion to kWh (1.8 kWh/litre). The figures in the table are samples but follow patterns commonly found in national oil and gas operations.

The table shows that electricity consumption is the largest component of energy use, while diesel consumption comes from internal generators (gensets), especially at facilities that are not connected to the PLN grid. Oil and gas production throughout the year appears to be relatively stable in the range of around 10.800 – 11.300 BOE.

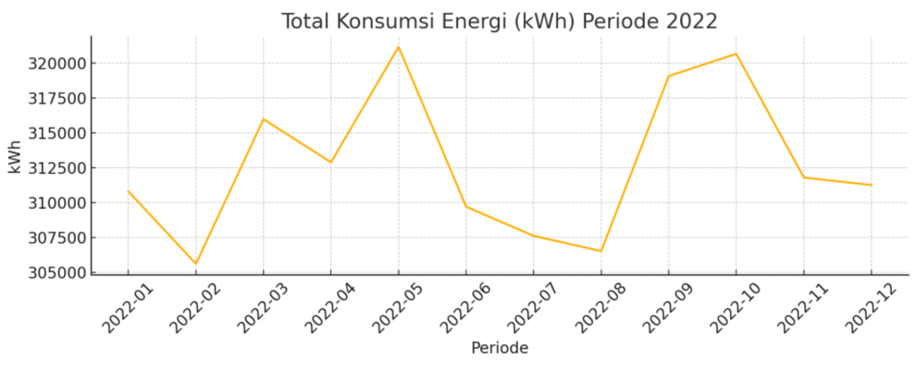

Fig. 1 below shows the total energy consumption trend during 2022.

The figure shows that monthly total energy consumption ranged from 305.000 to 321.000 kWh. This relatively stable pattern is a common characteristic of oil and gas facilities that operate continuously. A slight increase in the second and fourth quarters reflects additional energy requirements due to increased production and equipment maintenance. This pattern is consistent with the IEA (2021) report, which states that the global oil and gas sector tends to have energy consumption trends that are not far from the operational baseline due to the high *fixed energy load* component.

Energy Baseline (Linear Regression)

The energy baseline is calculated using linear regression between production (BOE) and total energy consumption (kWh). Table 2 shows the regression summary results.

Table 2. Energy Baseline Regression Summary

Parameter	Value
Slope (kWh/BOE)	29.504
Intercept (Baseload, kWh)	-14.244
R	0.942

The slope indicates the variable energy per unit of production. This means that each additional BOE requires approximately 29.5 kWh of energy. This value is reasonable for oil and gas facilities that operate pumps and compressors with moderate efficiency.

Negative **intercepts** should be interpreted with caution. In the context of nationally aggregated sample data, intercepts do not always represent *the baseload* of individual facilities. This may occur because:

- the sample data is the result of general pattern adjustments,
- production and energy trends are highly linear,
- data variation is minimal, causing the regression line to nearly intersect the origin.

In real facility studies, the intercept is usually positive

A high **R^2 value** indicates that energy variation is strongly influenced by production variation at the sectoral level. This is consistent with the findings of the IEA [2], which states that energy consumption in the oil and gas sector is strongly correlated with production volume at integrated facilities.

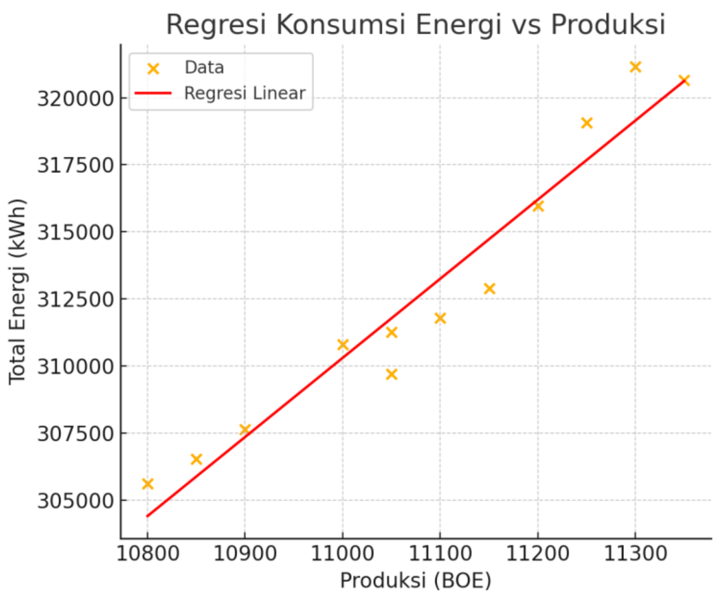

Fig. 2 below shows the regression relationship between energy consumption and production.

The graph shows data points (production vs energy) that form a strong linear pattern. The regression line is very close to these points, confirming a high R^2. This graph shows that sample data with realistic patterns can validly model the energy–production relationship for methodological purposes.

Specific Energy Consumption (SEC)

SEC is calculated from total energy per production. In this sample dataset, SEC is in the range of 28.0–28.4 kWh/BOE, indicating stable energy intensity.

- Stable SEC values ⇒ relatively efficient production operations
- SEC increases when production decreases (fixed load effect)
- SEC decreases when production increases (economies of scale)

This pattern is common in oil and gas facilities with large static utility components.

Energy Conservation Scenario Results

The scenarios were calculated based on *baseload* improvements and variable energy efficiency improvements. The results are presented in Table 3.

Table 3. The results are scenarios calculated based on baseload improvements and variable energy efficiency improvements

Scenario	Baseload Savings (MWh)	Technology Savings (MWh)	Total Savings (MWh)	CO2 Reduction (tonnes)
Moderate	-17,092	196,202	179,109	152.24
Aggressive	-34,186	588,605	554,419	471.26

Policy Interpretation and Implications

The scenario results show that the greatest energy savings are achieved through improved technological efficiency, rather than through baseload reduction. This is consistent with the findings of the IEA [2], which states that rotating equipment such as pumps and compressors have the most significant efficiency potential. The aggressive scenario provides energy savings of more than 550,000 MWh/year, while the moderate scenario results in savings of more than 170,000 MWh/year. Both show a real contribution to reducing CO_2 emissions and supporting the implementation of PP 33/2023 and Permen 3/2025.

Conclusion

This study analyses energy consumption in the oil and gas sector using national secondary data and a quantitative approach through *specific energy consumption* (SEC) calculations, baseline regression, and energy conservation scenarios. The analysis results reveal several key points. First, energy consumption in the oil and gas sector in 2022 was relatively stable, with total monthly energy consumption ranging from 305,000 to 321,000 MWh. This pattern is in line with oil and gas production, which was also stable, indicating that operations tended to be constant. Second, the SEC value ranged from 28.0 to 28.4 kWh/BOE, indicating that the energy intensity of the oil and gas sector was fairly consistent throughout the year. This suggests that variations in energy consumption were more influenced by variations in production than by changes in efficiency. Third, linear regression shows a strong relationship between energy and production with an R^2 value of around 0.94. The regression slope describes the energy variable at around 29.5 kWh/BOE, while the intercept is close to zero, indicating that the aggregate data does not accurately represent *the baseload* of individual facilities. Fourth, the energy conservation scenarios show significant savings potential. The moderate scenario provides savings of approximately 179,000 MWh/year, while the aggressive scenario achieves more than 550,000 MWh/year. Both result in substantial and economically viable CO_2 emission reductions. In general, this study concludes that the oil and gas sector has substantial energy conservation opportunities, particularly through improved technological efficiency. Baseline models and scenarios based on secondary data have proven effective in supporting the evaluation of energy conservation policy implementation, particularly PP 33/2023 and Permen 3/2025.

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