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Efficiency of U.S. Oil and Gas Companies toward Energy Policies

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Abstract: The petroleum industry faces crucial environmental problems that exacerbate business instability, such as climate change and greenhouse gas emission regulations. Generally, governments focus on pricing, environmental protection, and supply security when developing energy policy. This article evaluates the technical efficiency of 53 oil and gas companies in the United States during the period 1998–2018 using the stochastic frontier analysis methods and investigates the degree to which energy policies influence the efficiency levels in these companies. Our empirical results show that the average technical efficiency of the 53 U.S. oil and gas companies is 0.75 and confirm that prices, production, consumption, and reserves of the U.S. petroleum and gas have a significant influence on technical efficiency levels. Specifically, our findings show that renewable energy and nuclear power contribute to explaining the distortion between the optimal and observed output of the U.S. oil and gas companies.

Keywords: technical efficiency; energy; environment; oil and gas companies; stochastic frontier analysis

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1. Introduction

Although the world is looking to emerge from a global recession, countries are also looking for the best solutions to improve economic performance and create employment in order to increase people's well-being. Global energy prices and demand have shown resilience during the recession, which has prompted policy-makers in energy-producing countries to consider the energy sector as a key factor for economic growth. The energy sector represents a significant share of the GDP in producing countries. However, the energy sector has a significant impact on the entire economy. In addition, energy is an important factor for almost any sector of the economy. Therefore, stable and acceptable energy prices promote development and sustain economic growth.

Energy is the engine of development and economic growth, but governments tend to focus on environmental protection, prices, and security of supply when setting energy policies [1,2]. Although the goal of employment and economic growth is difficult to achieve, perhaps increasing employment directly in the energy sector is not the right decision if it raises energy prices and lowers the industry's overall productivity. Instead, welfare is more likely to be improved by focusing on how energy policies contribute to improving the overall economy and not just on the energy industry's direct contribution to the economy. In some countries, the petroleum industry contributes significantly to employment and economic growth.

The U.S. oil and gas extraction sector (energy industry) increased at a rate of 4.5% in 2017 versus a GDP growth rate of 1.7%. The U.S. is a world leader in energy manufacture and distribution, as well as one of the world's top energy users. The energy industry in the U.S. is the third largest in the world. Oil, natural gas, coal, nuclear power, sustainable sources and fuels, and electrical services are all produced by U.S. energy businesses, which also supply energy and electricity technology across the world. U.S.-made energy and electricity equipment dominates the domestic market and commands a strong market share abroad.

The U.S. is expected to become the world's largest producer of combined oil and gas. Since the oil crises of the 1970s, the U.S. energy policy has been based on the resource scarcity in the United States. This has resulted in strong support for open and transparent global energy markets, which are expected to reduce high and volatile prices for U.S. customers and allow U.S. companies to access foreign energy supplies.

Following the increase in the new technology exploration for environmental protection and energy efficiency, company managers face great pressure to invest in this technology and take necessary action and decisions to promote the company's sustainability. Furthermore, they are also keen to make a high profit for shareholders and to stay in a competitive global market. Therefore, company managers need to strike a balance between, on the one hand, operational and financial success and, on the other, environmental protection, as this balance ensures companies remain in a competitive global market and maintain a reputation. Generally, consumers prefer environmentally conscious services and products and avoid products from companies that are not environmentally friendly. Therefore, companies must comply with the latest environmental regulations.

This article aims to examine the impact of national energy policies on the technical efficiency of oil and gas companies in the U.S. The efficiency of oil and gas companies has been well studied in energy literature, but most of these studies have rarely investigated the explanatory variables of oil and gas companies' inefficiency.

The remainder of this research is structured as follows. Section 2 presents the literature review. Section 3 discusses methodology. Section 4 provides the data and discusses variables. Section 5 presents empirical results on technical efficiency measures for the U.S. oil and gas companies and discusses the inefficiencies determinants. Section 6 provides the conclusions and suggests future research.

2. Literature Review

Several studies have looked at the issue of oil and gas companies' efficiency. The research of Jarboui [1] examined the environmental and operational efficiencies and evaluated the inefficiency determinants for the desirable (operational revenue) and undesirable (CO_2 emission) outputs of 45 U.S. oil and gas companies during the period 2000–2018 and revealed the effect of different renewables energies. This research applies the true fixed-effect model under the framework of the SFA approach to measure the environmental and operational efficiencies. The results of this study reveal that the annual average scores of environmental and operational efficiencies have the same tendency during the study period. However, the gap between the operational efficiency level and the CO_2 emissions level are greater when the annual average scores of operational efficiencies exceed 75% or when its curve is ascending. The empirical findings reveal that the total production of renewable energy and the total production of biomass energy contribute to reduce the operational efficiency of oil and gas companies and contribute to the improvement of the environmental efficiency of oil and gas companies. Kazemitash et al. [3] applied the rough best–worst method for weighing and supplier evaluation with respect to information system performance and environmental impacts.

Atris and Goto [4] looked at two types of efficiency measures (operational and environmental) for 34 U.S. oil and gas companies from 2011 to 2015. Their study measured efficiency by applying data envelopment analysis (DEA) models to the data set. The results of this study showed that integrated companies outperformed independent ones in environmental efficiency. They explained this result through the higher standards of environmental protection in integrated companies and their efforts in strategic brands targeting the consumer to promote sales.

To assess the effect of renewable energies on the two types of efficiency, Jarboui [2] used two methods, the true fixed-effect model applied for measuring the efficiency scores and evaluating the inefficiency determinants, and the generalized method of moments (GMM) approach to verify the effect of energy and environmental policy on both types of efficiency of oil and gas companies. For a period of 19 years, Jarboui [2] revealed that the average operating efficiency was 76%, while the average CO_2 emissions efficiency was 79%. The findings show that in recent years, U.S. oil and gas businesses have begun to move to lower CO_2 emissions. Moreover, biofuel, hydroelectric power, wind power, and solar energy contribute to promoting the environmental efficiency of oil and gas companies.

Larsen et al. [5] investigated the efficiency of the U.S. energy service company industry considered as an example of a private sector business model. When the growth of the energy service company industry was slow and in decline, the industry continued to provide efficient energy services to several market sectors even as it faced high financing costs. This research confirms that the industry has evolved by relying on more comprehensive standards and measures including on-site construction and measures to address deferred maintenance, but this evolution has significant implications for customer project economics. The authors indicate that U.S. energy service companies are still able to deliver cost-effective energy solutions to their customers as evidenced by the significant net economic benefits generated by projects.

There is a large body of related literature that considers the governance mechanisms as important sources or determinants of the oil and gas companies' efficiency [6,7]. Kashani [8] suggests that the performance in the United Kingdom Continental Shelf (UKCS) petroleum activity has suffered inefficiencies and that the main responsibility for the inefficiency rests with the inefficient use of inputs. The author supports a great interest to incorporate the oil price and tax systems of various periods to distinguish between the effect of these and government interventions on the efficiency of the oil companies. Using DEA, stochastic frontier analysis (SFA), and Malmquist indices, the results prove an important insight into the UKCS production techniques and, more generally, into governments' abilities to influence private sector behavior through contracts and tendering. These results are similar to the results of Kashani [9], who explains the inefficiencies of the Norwegian Continental Shelf (NCS) by the state intervention.

Contrary to a large number of ownership studies in general, there is limited research so far specifically on the oil and gas industry. The framework of Al-Obaidan and Scully [10] is among the first studies that explore the efficiency differences between 44 private and state-owned U.S. oil companies. After controlling the levels of operational and multinational integration of the companies, they found that national oil companies (NOCs) are, on average, only 61% to 65% as technically efficient relative to private companies.

Particularly, Eller et al. [11] demonstrated, using both non-parametric and parametric techniques, that institutional features reflecting some non-commercial set of objectives facing a firm are important in explaining how well that firm produces revenue for a given set of inputs. Using the DEA method, they calculate an average efficiency score for NOCs of 0.27, compared to an average efficiency of 0.40 and an average efficiency score for the five largest private firms of 0.73. Thus, the relative technical inefficiencies of various NOCs, which are observed when one considers only commercial objectives, are largely the result of governments exercising control over the distribution of rents. The authors indicate that if an increasing proportion of global oil and gas resources are under the control of NOCs, it is reasonable to expect that an increasing majority of oil and gas developments will be driven with political objectives in mind.

Wolf [12] investigates the comparison of performance and efficiency between NOCs and privately owned IOCs (International Oil Companies) during the period 1987–2006. Using panel regression, the results confirm that NOCs are significantly underperforming the IOCs in terms of production efficiency and profitability. Additionally, the authors indicate that the NOCs produce a significantly lower annual level than the reserves. However, this cannot be an indication of the company's efficiency. The author explains that this might be caused by a more conservative depletion policy (intentional or not), a systematic overstatement of reserves, or by a combination of the two, and intentionally low production rates might not necessarily indicate lower productivity or efficiency at state-controlled firms. The finding results of Wolf [12] suggest that ownership effects exist in the oil and gas industry and that a political preference for state oil usually comes at an economic cost.

Eller et al. [11] explain the revenue inefficiency of NOCs for 78 firms worldwide, including 10 of the 12 member nations of OPEC and private international oil companies (IOCs), by using DEA and stochastic frontier revenue efficiency measures, whose results found that the NOC's non-commercial objectives tend to reinforce each other in their impact on employment profitability and timing of cash flows. Eller et al. [11] found that NOCs are less efficient than IOCs and that this inefficiency may be addressed by variations in the firms' institutional and structural aspects, which may occur as a result of divergent goals of the companies. Their results confirm the results of Wolf [12].

Eller et al. [11] also confirmed that the relative revenue inefficiencies of various NOCs are largely the result of governments exercising control over the distribution of rents and the notion that non-commercial government objectives negatively affect the ability of a NOC to generate revenue. In fact, the government overseers of such firms tend to redistribute resource rents toward both domestic consumers and domestic employees of the companies. The authors indicate that it is reasonable to expect that an increasing majority of oil and gas developments will be undertaken with political objectives in mind when an increasing proportion of global oil and gas resources are under the control of NOCs.

Several methods have been used to evaluate the efficiency of oil and gas companies. Non-parametric and parametric frontiers are the two main methods adapted to measure technical efficiency [7,13]. The non-parametric method, the DEA method developed by Farrell [14] and Charnes et al. [15], is formed as piecewise linear combinations that connect the set of best-practice observations, giving a set of convex production possibilities. Contrary to the SFA method, the DEA method does not require an explicit specification of the underlying production form. However, non-parametric approaches do not allow random error. If there is a random error, the measured efficiency can be confused with these random deviations from the true efficiency frontier. In addition, statistical inference and hypothesis tests cannot be performed for the estimated efficiency scores [16]. The parametric frontier method [13,17–19] establishes a production functional form between inputs and outputs and allows a random error. Inefficiencies and random errors are assumed to be orthogonal to the input or output determined in the estimation equation [16,20].

Referring to the above analysis, this research aims, firstly, to investigate the efficiency of 53 U.S. oil and gas over the period 1998–2018 and, secondly, to discuss the orientations of energy and environmental policies toward the efficiency of oil and gas companies, in another way, identifying the inefficiencies determinants of U.S. oil and gas companies using U.S. energy policy (oil, natural gas, renewable energy, and nuclear energy). This research adopted the stochastic frontier analysis model to evaluate the efficiency.

3. Methodology

This research uses a parametric approach with an SFA model of production function for the panel data, as developed by Battese and Coelli [21]. SFA is used as an alternative approach to data envelopment analysis (DEA), with the advantage of not only measuring technical inefficiency but also recognizing the effect of random shocks, beyond the control of producers, on production. For this reason, the SFA essentially involves an error term composed of two parts: one unilateral component that describes the effects of the relative inefficiency of the stochastic frontier and a symmetric component that allows a random variation of the frontier between companies and includes the effects of measurement error, other statistical noise, and random error [6,22].

3.1. Stochastic Frontier Analysis Model

We employed the stochastic frontier method of the production function for panel data developed by Battese and Coelli [21]. The starting point of this parametric method is to estimate a stochastic production frontier. This frontier can be written as follows (Equation (1)):

$$Y_{it} = exp(x_{it}\beta + V_{it} - U_{it}) \tag{1}$$

where Y_{it} is the output of the i-th oil and gas company (i = 1, 2, ... , N) in the t-th period (t = 1, 2, ... , T); x_{it} is a (1 × k) vector of input quantities of the i-th oil and gas company in t-th period; β is a (k × 1) vector of unknown parameters to be estimated; V_{it} is a random variable, which is assumed to be iid N (0, σ_V^2) and independent of U_{it}; the U_{it} is a non-negative random variable, associated with production inefficiency, which is distributed independently as truncations at 0 of the N (μ, σ_U^2) distribution, where $\mu = z_{it}\delta$ and variance σ_U^2 and z_{it} is a (1 × p) vector of explanatory variables associated with inefficiency of the oil and gas company production industry over time, where δ is a (p × 1) vector of unknown parameters.

The stochastic frontier production function is defined by Equation (1) in terms of the initial production values. The inefficiency consequences are represented by U_{it}; however, it might be the result of a set of explanatory variables, z_{it}, and a vector of coefficients, δ.

The inefficiency effect, U_{it}, in the model of the stochastic frontier method (1) is specified by Equation (2),

$$U_{it} = z_{it}\delta + W_{it} \tag{2}$$

where the random variable W_{it} follows truncated normal distribution with mean zero and variance σ^2, such that the point of truncation is $-z_{it}\delta$, that is, $W_{it} > -z_{it}\delta$. These assumptions are consistent with U_{it} being a non-negative truncation of the N ($z_{it}\delta$,σ_U^2) distribution [22]. The mean $z_{it}\delta$ of the normal distribution, which is truncated at zero to obtain the distribution of U_{it}, is not required to be positive for each observation.

In this study, the functional form of the translog production function was adopted to estimate the production frontier. This functional form is more preferable than the Cobb–Douglas form because the underlying technologies are flexible. The translog functional form allows the real function curve to be shown, rather than requiring assumptions [22]. This can be expressed by Equation (3).

$$lnY_{it} = \alpha_0 + \sum_{j=1}^{M} \alpha_j lnx_{jit} + \frac{1}{2}\sum_{j=1}^{M}\sum_{K=1}^{M} \alpha_{jk} lnx_{jit} lnx_{kit} + V_{it} - U_{it} \tag{3}$$

3.2. Inefficiency Modeling

The originality of this research is related to the introduction of the different variables of energy policy and oil and gas market in explaining the shortfall between the optimal and the observed frontier. We use an ensemble of variables to reflect U.S. oil and gas statistics and the nuclear and renewable energy consumption and production of the U.S. that are supposed to influence the efficiency of oil and gas companies, a random part associated with the unobservable factors. Consequently, the inefficiency model is defined by Equations (4)–(6) in 3 models.

Model 1:

$$\begin{aligned}\mu_{it} = \delta_0 + \delta_1(Petroleum\ Price)_{it} + \delta_2(Petroleum\ Prod.)_{it} + \delta_3(Petroleum\ Stocks)_{it} + \\ \delta_4(Petroleum\ Reserves)_{it} + \delta_5(Petroleum\ Consump.)_{it} + W_{it}\end{aligned} \tag{4}$$

Model 2:

$$\begin{aligned}\mu_{it} = \delta_0 + \delta_1(Nat.\ Gas\ Price)_{it} + \delta_2(Nat.\ Gas\ Prod.)_{it} \\ +\delta_3(Nat.\ Gas\ Reserves)_{it} + \delta_4(Nat.\ Gas\ Consump)_{it} + W_{it}\end{aligned} \tag{5}$$

Model 3:

$$\mu_{it} = \delta_0 + \delta_1\ (Nuclear\ prod)_{it} + \delta_2(Renewable\ Energy\ prod)_{it} + \delta_3(Nuclear\ consump)_{it} + \delta_4(Renewable\ Energy\ Consump)_{it} + W_{it} \quad (6)$$

4. Data

In this study, the data consist of 1050 annual observations. We used unbalanced panel data of 53 U.S. oil and gas companies between 1998 and 2018. We used the Thomson Financial Database to calculate the inputs, outputs, and U.S. Energy Information Administration to calculate the explanatory variables of inefficiency. Thomson financial databases provide different data types for many companies in different countries. Total assets and revenue data are directly available in the Worldscope database. The number of employees was calculated from this database by dividing the annual sales by the sales per employee. The oil and gas data of the U.S. and nuclear and renewable energy of the U.S. are directly available in the U.S. Energy Information Administration, which indicates the official energy statistics from the U.S. government.

The descriptive statistics of the variables used in this study are reported in Table 1, and all variables were adjusted by the application of logarithm. "Panel A" represents the variables of the production function frontier. Therefore, the average revenue of 53 firms between 1998 and 2018 was USD 18.654 million with a standard deviation of USD 3.793 million. The average total assets and number of employees was, respectively, USD 18.60 million and 5 employees with a standard deviation of USD 3.49 million and 3 employees.

Table 1. Descriptive statistic of all used variables.

Variables	**Mean**	**S.D.**	**Min.**	**Max.**
Panel A				
Net revenues (million USD)	18.6540	3.7934	5.7071	26.7952
Total assets (million USD)	18.6008	3.4909	11.9516	26.6616
Number of employee (persons)	5.0372	2.9561	0.0000	11.4917
$(OperExp)^2$	179.0797	67.7074	71.4198	355.4196
$(NmbreEmp)^2$	17.0501	17.4421	0.0000	66.0296
Exp × Emp	103.5572	77.6241	0.0000	301.6941
Panel B				
Petroleum price	3.8592	0.5970	2.6686	4.6019
Petroleum reserves (trillion tons)	9.9941	0.0691	9.8585	10.1866
Petroleum consumption (trillion tons)	9.8878	0.0374	9.8285	9.9428
Petroleum production (trillion tons)	9.1131	0.0760	9.0261	9.3160
Natural gas price	1.5170	0.4284	0.7372	2.1815
Natural gas consumption (trillion tons)	3.1578	0.0411	3.1018	3.2605
Natural gas production (trillion tons)	3.0135	0.0776	2.9208	3.2024
Natural gas reserves (trillion tons)	2.1904	0.0219	2.1668	2.2385
Nuclear production (trillion Btu)	2.0913	0.0454	1.9556	2.1348
Renewable energy production (trillion Btu)	1.8938	0.1448	1.6417	2.2231
Nuclear consumption (trillion Btu)	2.0913	0.0454	1.9556	2.1348
Renewable energy consumption (trillion Btu)	1.8932	0.1420	1.6415	2.2121

"Panel B" presents the explanatory variables used to explain the inefficiency term presented in model 4. The explanatory variables reflect two categories: first, national and global oil and gas factors such as oil and gas production, oil and gas reserves, oil and gas prices; and secondly, U.S. energy and environment policies reflected by nuclear production and consumption, and renewable consumption and production.

5. Empirical Results

5.1. Stochastic Frontier Analysis Results

The value of γ is significantly different from one indicating that random shocks play a significant role in explaining the variation in U.S. oil and gas companies' production, which is expected in the U.S. where uncertainty is assumed to be the main source of variation. This implies that the stochastic production frontier is significantly different from the deterministic frontier, which does not include a random error.

For the ML estimation, γ is positive and significant at a 1% level, implying that U.S. oil and gas industry-specific technical efficiency is important in explaining the total variability of yield produced. However, it should be noted that 99% of the variation in production is due to technical inefficiency, and only 1% is due to the stochastic random error.

This study specifies three translog stochastic frontier production models to evaluate the efficiency of U.S. oil and gas companies. Table 2 presents the results from several estimations of the stochastic frontier model given in Equation (3). Table A1 shows the results of estimated parameters from maximum likelihood (MLE). The analysis revealed several input variables that are significant determinants of companies' production. The result shows that there is a positive relationship between the used inputs and U.S. oil and gas companies' production. From the coefficients reported in Table 2, we can see that the total assets are the most important input with coefficients equal to 7.657, 8.079, and 7.555, respectively, in the three models. They are positive and statistically significant at the 1% level across all models. Moreover, the coefficients of the number of employees are positive and statistically significant at a 5% level. However, the square effect of total assets is negative and statistically significant at a 5% level. Therefore, the square effect of the number of employees is not significant in all estimated models. These results confirm the work of Atris and Goto [4].

Table 2. Estimated parameters of the translog SFA production function.

Variable	Parameters	Estimated MLE Coefficients		
		Model 1	**Model 2**	**Model 3**
Constant	α_0	−1.075 (−1.027)	−1.317 (−1.294)	−0.924 (−0.891)
Ln total assets	α_1	1.190 (7.659) ***	1.207 (8.079) ***	1.165 (7.555) ***
Ln number of employees	α_2	0.033 (2.091) **	0.071 (2.057) **	0.0718 (2.084) **
(Ln total assets)^2	α_3	−0.011 (−1.931) **	−0.010 (−1.945) **	−0.0089 (−1.728) *
(Ln number of employees)^2	α_4	−0.016 (0.738)	−0.028 (−1.360)	−0.0223 (−0.858)
(Ln total assets) × (Ln number of employees)	α_5	0.973 (2.024) **	0.885 (2.097) **	0.869 (2.030) **
Constant	δ_0	5.913 (4.033) ***	4.301 (2.222) **	3.685 (2.121) **
Petroleum price	δ_1	−0.048 (6.071) ***	- -	- -
Petroleum reserves	δ_2	0.022 (6.214) ***	- -	- -
Petroleum consumption	δ_3	−0.017 (−2.285) **	- -	- -
Petroleum production	δ_4	−0.032 (−6.332) ***	- -	- -
Natural gas price	δ_6	- -	−5.928 (2.655) ***	- -
Natural gas consumption	δ_7	- -	−7.198 (−2.023) **	- -
Natural gas production	δ_8	- -	−21.683 (2.257) **	- -
Natural gas reserves	δ_9	- -	28.131 (2.171) **	- -
Nuclear production	δ_{10}	- -	- -	15.068 (4.360) ***
Renewable energy production	δ_{11}	- -	- -	6.929 (5.277) ***
Nuclear consumption	δ_{12}	- -	- -	15.068 (4.360) ***
Renewable energy consumption	δ_{13}	- -	- -	9.657 (4.776) ***
Sigma-squared	$\sigma^2 = \sigma_V^2 + \sigma_U^2$	11.172 (6.616) ***	12.999 (2.600) ***	15.142 (4.087) ***
Gamma	γ	0.989 (472.586) ***	0.990 (251.092) ***	0.991 (549.088) ***
Log likelihood function		−664.944	−666.967	−628.307

*, **, and *** significant at the 10%, 5%, and 1% levels, respectively.

The second objective of this research is to identify the technical efficiency determinants of U.S. oil and gas companies. Therefore, the results of the technical inefficiency effects model are presented in Table 2. Model 1 and 2 show that the inefficiency of the U.S. oil companies can be explained by the variation of oil and gas price, oil and gas production, oil and gas consumption, and oil and gas reserves of the U.S. (see Table 2). The estimation parameters δ_1 and δ_6 show that the variation of oil and gas prices has a significantly negative effect on the inefficiency of the U.S. oil and gas companies and, therefore, promotes the company's efficiency. This result can be explained by the fact that the rising prices of oil and gas increase the cash flows and the profits of oil and gas companies and facilitates their investments, which leads to improvement of the efficiency. Simultaneously, during the falling of oil and gas prices, the major oil companies are forced to invest in equity and cannot continue to finance their projects leading to a reduction in their profit margin and the deterioration of their efficiency. During the oil crisis of 2008–2009, the falling oil price caused difficulties of refinancing and illiquidity problems for oil and gas companies leading to the decline in oil demand. For the petroleum industry, high-oil-price periods, generally, imply higher profits and increasing cash flows.

The reserves of oil and gas of the U.S. oil and gas companies are not only the reserves of U.S. but include a significant proportion of world reserves of many countries (Gulf of Mexico, Canada, UK, Angola, Gulf Cooperation Council, etc.). Nevertheless, the estimated parameters δ_2 and δ_9 show that the variation of U.S. petroleum and natural gas reserves has a significantly positive effect on the inefficiency and also a negative effect on the efficiency of U.S. oil and gas companies. In fact, the demand for energy consumption is increasing as the price of oil and gas increases due to the global economic growth, driving the depletion of global oil reserves, especially for international companies' producers of oil and gas. During the period of 2002–Mi 2008, we show a low level of U.S. oil and gas reserves because of the increased demand for energy due especially to the economic growth of several emerging countries (China, Brazil, India). This positively affected the efficiency of U.S. oil and gas companies.

After the financial crisis of 2008 and its negative impact on the global energy consumption due to the economic recession, we show that the U.S. oil and gas reserves decreased, and the inefficiency of U.S. oil and gas companies increased. This is explained by the global economic recession, which resulted in declining global energetic demand. According to Table 2, the estimated coefficients $(\delta_3 = -0.071; \delta_7 = -7.198)$ show that the variation of petroleum and natural gas consumption of U.S. has a significantly negative effect on the inefficiency of U.S. oil and gas companies. Therefore, the estimated coefficients $(\delta_4; \delta_8)$ show that the variation of petroleum and natural gas production of U.S. negatively affects the inefficiency of U.S. oil and gas companies.

The estimation parameters δ_{11} and δ_{13} show that the variation of the renewable energy production and consumption of U.S. has a significantly positive effect on the inefficiency of U.S. oil and gas companies. Furthermore, the estimated coefficients $(\delta_{10}; \delta_{12})$ show that the variation of the nuclear production and consumption of U.S. positively affected the inefficiency and, therefore, negatively the efficiency of U.S. oil and gas producers. This can be explained by the strategy adopted by the U.S. government, after the oil and financial crises of 2008 the level of oil price volatility was higher. The U.S. government has oriented to renewable energy and nuclear energy in order to decrease their energetic dependence.

The results presented above clearly show that the efficiency of oil and gas companies is affected by global factors, namely the price of oil and gas, but especially affected by the orientations of U.S. energy policies, which are oriented toward environment protection and bio-energy. Generally, energy consumption in the United States follows the same energy production trends over the past 50 years. In the United States, petroleum is the largest source of energy production and consumption, but percentages of energy consumption from petroleum have decreased from 43% in 1957 to 37% in 2018. Natural gas has grown from 24% to 32% of energy consumption in the United States. Renewable energies and nuclear power represent larger shares of consumption now than in 1957, but the share of coal has fallen from 26% to 11% since then. The expected increases in natural gas costs, as well as the increase in renewable energies, contribute to a 2.3% decrease in natural-gas-fired production. U.S. coal generation fell by 3.2%. Renewable energy consumption, which includes renewable-powered electricity generation, biomass, and biofuels, increased by 88% during the period 2000–2018.

Since the Kyoto Protocol (UNFCCC) was adopted in 1997, and more recently, the "Paris Agreement" proposed in 2015 has marked a global consensus on global warming, the recourse to the use of renewable energies and nuclear energy has become evident in the U.S. energy policy, which is evidenced by most statistics of the production of renewable energies, which has greatly contributed to affecting the efficiency of U.S. oil and gas companies, as shown by the results of this study.

5.2. Efficiency Analysis of Selected U.S. Oil and Gas Companies

Technical efficiencies scores of the sample oil and gas companies estimated by the SFA model are shown in Table A1. The average technical efficiency score of U.S. oil and gas companies during the period 1998–2018 is 0.76 while the minimum and maximum technical efficiency scores are 0.39, as recorded by "Glen Rose Petroleum Corporation (GLRP)", and 0.99, as recorded by the "Reserve Petroleum Company (RSRV)". Based on these results, the standards deviations of efficiency scores are generally high, reflecting that the level of technical efficiency of U.S. oil and gas companies was generally volatile during the period of study. However, the technical efficiency score of some firms experienced an increasing trend (see Table A1), for example, "Petroquest Energy, Inc. (PQ)" (from 0.13 to 0.90), or a decreasing trend, for example, "Royale Energy, Inc. (ROYL)" (from 0.88 to 0.42).

Although the U.S. petroleum industry is made up of many companies, for many, the face of the petroleum industry is represented by the big five companies operating largely in the United States market. These companies are Chevron, ExxonMobil, Royal Dutch Shell plc, BP plc, and ConocoPhillips. The oil and natural gas production of American companies exhibited a high level of efficiency above 50% except for FX Energy, Gasco Energy, Evolution Petroleum Corporation, Daleco Resources Corporation, Aztec Oil & Gas, Adino Energy Corporation, Altex Industries, and American Eagle Energy Corporation.

The average efficiency scores during the period of study are presented in Table 3 and Figure 1. The results of this study show that the U.S. energy sector recorded the highest efficiency scores of oil and gas companies in 2005 with a score of 0.8443 and during the period 2014–2016 with scores of 0.8571, 0.9010, and 0.8246, respectively. In contrast, the U.S. energy sector recorded a drop in efficiency scores in 2008 with a score of 0.6216 and in 2009 with a score of 0.5760. The trend of annual efficiency scores of U.S. oil and gas companies essentially reflects the oil prices' evolution. Over the period 2007 to 2011, oil prices were volatile. They increased to a record peak in 2008, declined rapidly in late 2008 and early 2009; increased in 2010; and remained high during the period reaching a record peak in 2015. The average oil and gas production efficiency of major U.S. companies followed a similar pattern. However, the production of oil and natural gas has remained largely modified in the face of price volatility, suggesting that the market price and the production of key commodities are closely related.

Table 3. Annual efficiency scores of U.S. oil and gas companies.

Period	Mean	Standard Deviation	Minimum	Maximum
1998	0.6484	0.1586	0.1368	0.8257
1999	0.7064	0.1696	0.0351	0.9207
2000	0.7969	0.1820	0.0428	0.9419
2001	0.7767	0.1603	0.0072	0.9191
2002	0.7326	0.1706	0.0258	0.9432
2003	0.7971	0.1587	0.1176	0.9351

Table 3. *Cont.*

Period	Mean	Standard Deviation	Minimum	Maximum
2004	0.7810	0.1861	0.0395	0.9392
2005	0.8440	0.1779	0.3138	0.9357
2006	0.7763	0.1958	0.0054	0.9228
2007	0.7357	0.2150	0.0413	0.9325
2008	0.6216	0.1812	0.0680	0.9301
2009	0.5760	0.1967	0.0130	0.9206
2010	0.7154	0.2095	0.0438	0.9354
2011	0.7816	0.1822	0.0466	0.9180
2012	0.7746	0.1550	0.1729	0.9406
2013	0.7457	0.2050	0.0403	0.9225
2014	0.8571	0.1812	0.0680	0.9321
2015	0.9010	0.1861	0.0395	0.9592
2016	0.8246	0.1958	0.0054	0.9228
2017	0.7664	0.1696	0.0351	0.9107
2018	0.7536	0.1586	0.1368	0.8057

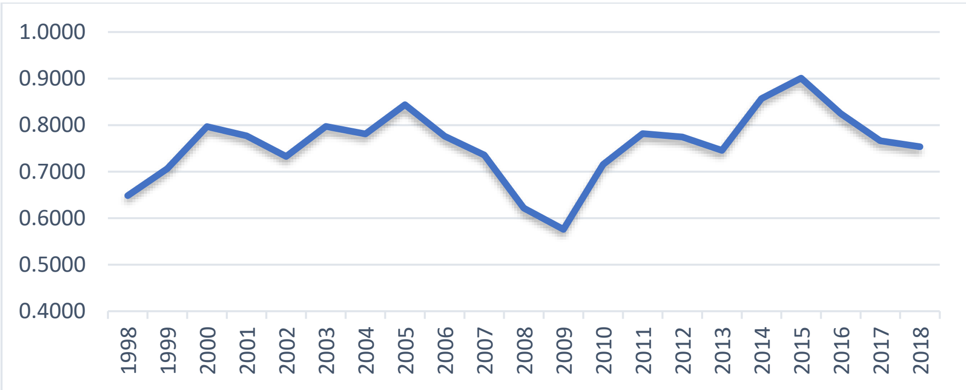

Figure 1. Average technical efficiency of U.S. oil and gas companies.

6. Conclusions

Oil products are critical to economic and political growth as a strategic resource. However, the petroleum industry faces crucial environmental problems that exacerbate business instability, such as climate change and greenhouse gas emission regulations. When creating energy policy, governments often focus on pricing, environmental protection, and supply security. The efficiency of oil and gas companies, on the other hand, is often forgotten or ignored.

This paper proposes a new explanation for technical efficiency distortions that derive from energy and environmental policies. Using stochastic frontier analysis (SFA) models, this study assessed the efficiency metrics for 53 U.S. oil and gas corporations from 1998 to 2018. It concentrated on the effect of U.S. energy policy to explain how such renewable energy, nuclear energy, and the different factors related to petroleum and gas production influence the technical efficiency of U.S. oil and gas companies.

The results of this study show that the average technical efficiency of the 53 U.S. oil and gas companies was 0.76 while the minimum and maximum technical efficiency scores were 0.39, as recorded by “Glen Rose Petroleum Corporation (GLRP)”, and 0.99, as recorded by the “Reserve Petroleum Company (RSRV)”. Prices, production, consumption, and reserves of the U.S. petroleum and gas all have a considerable impact on technological efficiency levels, according to our empirical findings. We also observe that renewable energy and nuclear power of the U.S. affect the technical efficiency levels of the U.S. oil and gas companies. Finally, this paper provides an overview of the U.S. energy policy and the effect of energy prices on the efficiency of the U.S. oil and gas producers during the period 1998–2018.

Since the Kyoto Protocol was enacted in 1997, and more recently, the "Paris Agreement" announced in 2015 has marked a global consensus on global warming, the recourse to renewable energies and nuclear energy has been obvious in U.S. energy policy, reducing the efficiency of oil and gas firms.

Because of the rise of renewable energy supplies, demand for petroleum products will decline, and energy usage will become more diverse. In other words, by substituting renewable energy sources for the need for heavy oil products used for heat and power generation, the transition of heavy oil products to light oil products may be hastened, and the overall efficiency of the oil industry can be improved.

Similar to any other research, this study also has some opportunities for improvement. Firstly, while the findings reveal that the efficiency of companies is associated with the best exploitation of the labor and capital factor used in this study, they also show that the efficiency is affected by the volatility of oil and gas prices, national or global supply and demand, and U.S. reserves. Secondly, the energy and environmental policies have a clear impact on the efficiencies of oil and gas companies. The U.S. has adopted several measures to reduce pollution, such as promoting renewable energy and energy conservation, which affects the efficiencies of oil and gas companies and contributes to explaining the distortion between optimal and observable output.

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Appendix A

Table A1. Efficiency scores of U.S. oil and gas companies.

	U.S. Oil and Gas Companies	Mean	Standard Deviation	Minimum	Maximum
1	ABRAXAS PETROLEUM CORPORATION (AXAS)	0.8155	0.0765	0.5968	0.9102
2	ADAMS RESOURCES & ENERGY, INC. (AE)	0.7803	0.0247	0.6515	0.8280
3	ADINO ENERGY CORPORATION (ADNY)	0.4835	0.2701	0.0395	0.9357
4	AMERICAN EAGLE ENERGY CORPORATION (AMZG)	0.4809	0.2617	0.0965	0.7803
5	ANADARKO PETROLEUM CORPORATION (APC)	0.8526	0.0705	0.6317	0.9389
6	APCO OIL & GAS INTERNATIONAL, INC. (APAGF)	0.8660	0.0317	0.7464	0.9160
7	BLUE DOLPHIN ENERGY COMPANY (BDCO)	0.6234	0.1607	0.2415	0.8406
8	CHESAPEAKE ENERGY CORPORATION (CHK)	0.8453	0.0569	0.6485	0.9278
9	CHEVRON CORPORATION (CVX)	0.7973	0.0458	0.6038	0.8472
10	CLAYTON WILLIAMS ENERGY, INC. (CWEI)	0.8162	0.0927	0.5135	0.9070
11	CRIMSON EXPLORATION, INC. (CXPO)	0.7492	0.1559	0.2503	0.8892
12	DALECO RESOURCES CORPORATION (DLOV)	0.4001	0.0969	0.1568	0.6452
13	DOUBLE EAGLE PETROLEUM CO. (DBLE)	0.7522	0.1168	0.4210	0.8826
14	EARTHSTONE ENERGY, INC. (ESTE)	0.8525	0.0561	0.6687	0.9217
15	Energen Corporation (EGN)	0.8143	0.0428	0.6440	0.8696
16	EPL OIL & GAS, INC. (EPL)	0.8106	0.0764	0.5685	0.8837
17	EVOLUTION PETROLEUM CORPORATION (EPM)	0.5306	0.2616	0.0671	0.9355
18	FOREST OIL CORPORATION (FST)	0.8445	0.0481	0.6541	0.9140
19	FX ENERGY, INC. (FXEN)	0.4597	0.1762	0.1755	0.7991
20	GASCO ENERGY, INC. (GSXN)	0.5081	0.2934	0.0072	0.8650
21	GATEWAY ENERGY CORPORATION (GNRG)	0.7367	0.0375	0.5782	0.7816
22	GLEN ROSE PETROLEUM CORPORATION (GLRP)	0.3999	0.2485	0.0130	0.7923
23	GOODRICH PETROLEUM CORPORATION (GDP)	0.7337	0.1297	0.3243	0.8737
24	GULFPORT ENERGY CORPORATION (GPOR)	0.8276	0.1172	0.3786	0.9316

Table A1. *Cont.*

	U.S. Oil and Gas Companies	Mean	Standard Deviation	Minimum	Maximum
25	MARATHON OIL CORPORATION (MRO)	0.7829	0.0646	0.5818	0.9103
26	OASIS PETROLEUM, INC. (OAS)	0.8332	0.0837	0.6185	0.9220
27	PANHANDLE OIL & GAS, INC. (PHX)	0.8605	0.0705	0.5923	0.9281
28	PDC ENERGY, INC. (PDCE)	0.7788	0.0754	0.4943	0.8871
29	PETROQUEST ENERGY, INC. (PQ)	0.7647	0.2109	0.1368	0.9010
30	PYRAMID OIL COMPANY (PDO)	0.7921	0.1020	0.3972	0.8894
31	ROYALE ENERGY, INC. (ROYL)	0.7563	0.0971	0.4206	0.8899
32	SM ENERGY COMPANY (SM)	0.8301	0.0825	0.5685	0.9090
33	SOUTHWESTERN ENERGY COMPANY (SWN)	0.8256	0.0474	0.6590	0.8869
34	SPINDLETOP OIL & GAS CO. (SPND)	0.8116	0.0958	0.5517	0.9202
35	STONE ENERGY CORPORATION (SGY)	0.8625	0.0516	0.6501	0.9360
36	STRAT PETROLEUM, LTD.	0.6253	0.2429	0.1911	0.9697
37	SWIFT ENERGY COMPANY (SFY)	0.8695	0.0503	0.6798	0.9429
38	TEXAS VANGUARD OIL COMPANY (TVOC)	0.8215	0.0465	0.6384	0.9072
39	THE RESERVE PETROLEUM COMPANY (RSRV)	0.9940	0.0286	0.8257	0.9998
40	VAALCO ENERGY, INC. (EGY)	0.7725	0.2910	0.1561	0.9932
41	ALTEX INDUSTRIES, INC. (ALTX)	0.5030	0.2636	0.0413	0.8182
42	APACHE CORPORATION (APA)	0.8822	0.0657	0.6686	0.9485
43	CHINA NORTH EAST PETROLEUM HOLDINGS LIMITED (CNEP)	0.8768	0.0827	0.6075	0.9325
44	CONOCOPHILLIPS (COP)	0.8024	0.0550	0.5999	0.8623
45	CHEVRON CORPORATION (CVX)	0.7975	0.0459	0.6038	0.8472
46	DEVON ENERGY CORPORATION (DVN)	0.8648	0.0425	0.7087	0.9187
47	EOG RESOURCES, INC. (EOG)	0.8626	0.0677	0.6597	0.9407
48	EXXON MOBIL CORPORATION (XOM)	0.8135	0.0408	0.6402	0.8607
49	MURPHY OIL CORPORATION (MUR)	0.7809	0.0267	0.6439	0.8192
50	NEWFIELD EXPLORATION COMPANY (NFX)	0.8616	0.0460	0.6995	0.9227
51	NOBLE ENERGY, INC. (NBL)	0.8486	0.0628	0.6388	0.9180
52	OCCIDENTAL PETROLEUM CORPORATION (OXY)	0.8513	0.0593	0.6268	0.9189
53	ZAZA ENERGY CORPORATION (ZAZA)	0.7313	0.1470	0.3695	0.9263

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