Assessment of Energy Efficiency Gaps: The Case for Ukraine

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Abstract: This article substantiates the need to find and implement innovative tools to improve the efficiency of the domestic system for energy sector control. The authors determined that energy policy renewal should consider Ukraine’s commitments to transition to a carbon-neutral economy. The systematization of scientific achievements shows that one of the priority tasks is to minimize the gaps in the energy efficiency of the national economy. It is established that, despite the significant scientific achievements in this area, the scientific community has not adopted a single approach to assessing energy efficiency yet. The purpose of this article is to assess the energy efficiency gaps in the national economy, in order to identify their peak values and the factors causing them, and appropriate mechanisms to minimize them. The energy efficiency gaps are assessed using frontal analysis and Shepard’s energy distance function. Analytical data from the World Bank, the Swiss Institute of Economics, and the International Energy Agency form the information base. The study applied software package Stata 14 for calculation the energy efficiency gaps for Ukraine for 2002–2019. The study applied the Shepard’s function translogarithmic, stochastic frontier analysis for the assessment of energy efficiency gaps. According to the study results, the average level of energy efficiency gaps is 0.12, and their values became the largest in 2009 and 2015. First of all, this is due to the impact of the global financial crisis and the escalation of military–political conflicts. The growing dynamics of the energy efficiency gaps level is due to the excess of the negative effect of increasing exports of primary energy resources and inefficient technologies for their processing over the positive impact of energy-efficient innovation imports. In this case, the government should provide a proactive strategy for creating a positive investment climate, in order to attract additional financial resources for extending green innovations and popularizing the green style and cultivate the energy safety behavior in society.

Keywords: gap; energy efficiency; energy policy; stochastic modeling

1. Introduction

The adoption of the concept regarding the green energy transition of the national economy necessitates the search for innovative tools to improve regulation of the domestic energy sector. At the same time, it is necessary to update energy policy considering the European Union’s (EU’s) requirements and standards. In this case, one of the priority tasks for the government is to find tools to minimize the energy efficiency gaps of the national economy through the increasing of energy efficiency of the national economy. In addition, the accepted EU vector of Ukrainian development and accepted Green Deal Policy requires the synchronization of the Ukrainian energy system and policy with the EU. Despite significant scientific achievements in this area, the scientific community has not adopted a single approach to assessing energy efficiency yet. The purpose of the article is to assess the energy efficiency gaps in the national economy, in order to identify their peak values and the factors causing them, as well as appropriate mechanisms to minimize them.
2. Literature Review

In prior papers [1], scientists have confirmed that the energy efficiency of the country is a key driver to transition into a green economy. At the end of the last century, scientists began to investigate the reasons for energy efficiency gaps. A theoretical example of this problem is the study of Jaffe and Stavins [2]. The authors try to explain the essence of the “energy efficiency gap”, and formulate the main criteria affecting optimal energy consumption. Scientists conclude that the gap in energy efficiency is the difference between the available and possible economic, technological, and social potentials of energy consumption.

The analysis of scientific investigations gives grounds to conclude that many scientists evaluate energy efficiency gaps as the difference between the potential and actual ability to generate and consume energy from a technological point of view. Thus, Lee and Lin [3] propose assessing energy efficiency gaps through technological and economic components. Gillingham and Palmer [4] follow a similar view. The authors substantiate that it is necessary to consider technological and economic indicators (labor and capital) in assessing energy efficiency gaps.

While assessing the energy efficiency gaps, scientists Zhang and Zhou [5] consider the geographical location of the China province, its economic indices, and its strategic development goals. The authors used panel data from 284 cities in China from 2003 to 2013 for empirical analysis. The obtained results showed that the regions’ economic development heterogeneity has a statistically significant impact on the volume of energy efficiency gaps. In other papers [6,7], scientists have proved that energy efficiency and energy efficiency gaps depend on economic structure, technological preconditions, and behavioral determinants.

Based on study results [8], this paper’s authors determined that the mechanism to compare the actual energy efficiency level with its previous value is the basis for assessing energy efficiency gaps. Thus, scientists [9] proposed evaluating energy efficiency using data envelopment analysis (DEA), based on data analysis of input–output energy use. The authors emphasized the expediency of combining two models: the traditional CCR (standard conventional model implication) and the extended SBM model. The results of the study show that a timely assessment of energy efficiency minimizes its gaps. Besides, there is a need to find alternative energy sources and their efficient combinations.

In their paper, Lin and Long [10] analyzed the energy efficiency of the country using the stochastic frontier analysis. Chai and Baudelaire [11], using the MOA approach, which provides an analysis of motivation, opportunities, and benefits for increasing energy efficiency, assess energy efficiency gaps. The authors focus on the first two components: “motivation” and “opportunities”. They used the data of a field survey conducted by the Institute of Energy Research of the National University of Singapore to confirm the hypotheses. Using structural modelling and the PL SM (partial least squares) method, the authors found out that the minimization of energy losses and the introduction of new technologies have a statistically significant positive impact on energy efficiency. At the same time, innovative technologies form the preconditions for raising the environmental awareness level. One should note that Chai and Baudelaire argued that compliance with the principles of the company’s corporate social responsibility and regulations does not significantly impact the volume of energy efficiency gaps at the company level.

Mier and Weisbart [12], analyzing the prospects for the development of the energy sector in the implementation of policies to decarbonize and minimize energy efficiency gaps, justify the feasibility of including demand for energy resources and the volume of attracted green investments in the energy model analysis, provided that the partial equilibrium of the energy market is achieved. Mier and Weisbart use the EU-REGEN model to describe the European electricity market. Thus, the authors determined that increasing energy efficiency in the short term reduces carbon emissions by 11% and creates the preconditions for lowering the energy efficiency gap in the long run. The authors also identified that volumes of energy generation from alternative sources have the most statistically significant impact on energy efficiency. Moreover, the development of alternative energy sources
provides the maximum reduction of energy efficiency gaps. Mier and Weisbart emphasize that attracting green investment minimizes energy efficiency gaps in the long run [12].

Considering the latest trends, scientists analyze energy efficiency gaps through corporate culture and knowledge sharing [13], green entrepreneurship [14], quality of business environment [15], waste management, and energy efficiency technologies [16–21]. In addition, a huge range of the countries have started transformation process on greening in all spheres for decreasing the energy efficiency gaps: tourism [22], the transport sector [23], and the industry sector [24,25].

Scientists have proven that the magnitude of energy efficiency gaps depends on regulation efficiency with regard to climate change policy [26–28], extending of renewable energy [29], macroeconomic stability [30], and transparency policies [31]. Each group of indices has some sub-indices for estimating the volume of energy efficiency gaps. It is worth noting that scientists [32–34] have used the different approaches to estimate energy efficiency gaps to relate the core determinates. In their work [33], Palmer and Wall assess the gaps in energy efficiency using the example of the American residential complex. In this case, the main indicator is the number of energy costs in energy consumption and transportation. The authors substantiate that the isolation of regulatory policy from the real functioning of the American housing complex and the energy market has provoked an increase in energy efficiency gaps. Scientists [35–43] have confirmed that a country’s favorable investment climate allows attracting additional investment in green technologies that increase the country’s energy efficiency.

Thus, the authors here propose to evaluate a set of indicators within each group of drivers:

- **Internal drivers include**
  - efficiency of technologies [44,45];
  - operating expenses;
  - access to capital;
  - organizational structure [46,47];
  - the level of environmental responsibility and awareness of the company’s administration regarding energy-efficient technologies [48–54];
  - innovativeness of energy-efficient technologies [55,56].
- **External drivers include**
  - level of competitiveness [57,58];
  - efficiency of power grids [59];
  - effectiveness of energy policies and regulatory interventions [60–67].

Scientists [67–76] have confirmed that macroeconomic indicators influence a country’s energy security and energy efficiency. Simultaneously, human capital and financial development have influenced CO₂ emissions and energy efficiency [67,68,71–86]. Malinauskaitė et al. [87] confirmed that energy efficiency of the industry sector has influenced the achievement of the goals of the Green Deal Policy. Akram et al. [88], using the ordinary least squares and fixed-effect panel quantile regression, proved that energy efficiency has had a statistically significant impact on carbon emissions for developing countries. Yang and Lam [89] confirmed the hypothesis that energy efficiency gaps appear due to low environmental responsibility and awareness of the non-market benefits of energy-efficient technologies. The authors used the contingent valuation method and probit analysis. Arbolino et al. developed their methods of increasing energy efficiency due to decreasing gaps between the local areas in Italy [90]. They developed a local energy efficiency index and used principal component analysis.

The analysis of the scientific and methodological approaches to assess energy efficiency gaps confirmed the existence of significant differences in practices, the inconsistency of the results, and the diversity of determinants considered during the assessment of the energy efficiency gaps. Therefore, it is necessary to find an approach for assessing energy efficiency gaps. The paper aims to develop approaches to estimate the energy efficiency
gap in the national economy. It would allow a country to identify its peak values and the factors causing them, and appropriate mechanisms to minimize them.

3. Materials and Methods

Considering the results of the analysis of the approaches to define energy efficiency gaps [2–12], the authors propose systematically combining the stochastic frontal analysis (SFA) and Shepard’s energy distance function to assess energy efficiency gaps. Traditionally, increasing efficiency theory involves optimizing the result by maximizing production and profits and minimizing costs. In general, the stochastic production frontier function can be written in the form of Formula (1):

\[
\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i
\]

where \(i = 1, \ldots, N\) and \(t = 1, \ldots, T\); \(u_i \geq 0\); \(y_{it}\) is the value of the resulting indicator of the \(i\)-th product per year (dependent variable); \(x_{nit}\) is the parameter of the resulting indicator of the \(i\)-th product for the period \(t\) (independent variables); \(u_i\) is the non-negative invariant random variable caused by technical inefficiencies; \(v_{it}\) is the random value of the \(i\)-th unit in the year \(t\), reflecting the effect of statistical noise; \(\ln\) indicates natural logarithm; and \(\beta_0, \ldots, \beta_n\) are the calculated parameters of the model.

Considering certain papers [2,11,12] the Cobb–Douglas function applies to estimation of the economic development of a country where the energy sources are the key driver. In the general Cobb–Douglas function [83],

\[
f(x, \beta) = \beta_0 \prod_{i=1}^{N} x_i^{\beta_i}
\]

where \(x\) represents the independent variable of the model, \(\beta_0, \ldots, \beta_i\) are the calculated parameters of the model and the output elasticity coefficient of the independent variables, \(i = 1 \ldots N\) is the number of input parameters of the model, and \(f(x, \beta)\) is the function of the output parameters.

The findings in previous papers [5,10,11] confirm that the translog function allowed elimination of the problem, with liner causal relationships between input and output. Thus, the translog function could be written as [83]

\[
f(x, \beta) = \beta_0 + \sum_{i=1}^{N} \beta_i \ln(x_i) + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{ij} \ln(x_i) \ln(x_j)
\]

where \(x\) is the input parameter of the model, \(i = 1 \ldots N\) and \(j = 1 \ldots N\) are the numbers of production factors, \(\ln\) is the natural logarithm, and \(\beta_0, \ldots, \beta_{ij}\) are the calculated parameters of the model.

Using the test results of the likelihood logarithms ratio, a number of authors [2,11,12,66] have emphasized the practical advantage of using the translog function. It relates to the possibility of considering the non-monotonic dependence of the output parameters on the input ones, the linearity of the transformation of the variable, and the relatively small number of estimated parameters.

In this study, energy efficiency gaps are estimated based on Shepard’s function (Formula (4)). Shepard’s function differs from the Cobb–Douglas function, mainly because it considers the amount of energy consumed along with capital and labor.

\[
PE = \frac{1}{DE(K, L, E, Y)}
\]

where \(DE(K, L, E, Y)\) is the Shepard energy distance function, \(K\) represents the volume of gross fixed capital in the country, \(L\) is the size of the working population, \(E\) is the amount of energy consumed in the country, \(Y\) is the gross domestic product of the country, and \(PE\) represents the number of energy efficiency gaps in the national economy.
Taking into account the specific nature of the frontal analysis and Shepard’s energy distance function, the translogarithmic, stochastic frontier model within this study is
proposed to be presented in the form of

\[-\ln E_t = a_0 + a_1 \ln K_t + a_2 \ln L_t + a_3 \ln Y_t + 0.5a_4 \ln (K_t)^2 + 0.5a_5 \ln (L_t)^2 + 0.5 + a_6 \ln (Y_t)^2 + a_7 (\ln K_t)(\ln L_t) + a_8 (\ln K_t)(\ln Y_t) + a_9 (\ln L_t)(\ln Y_t) + \beta_0 T + \beta_1 T^2 + \beta_2 (\ln K_t) + \beta_3 (\ln L_t) + \beta_4 (\ln Y_t) + \beta_5 (T)(\ln Y_t) + \theta t - \mu t\]

where \(a_0 \ldots a_9, \beta_0 \ldots \beta_5, \gamma_0 \ldots \gamma_2\) are the model constants; \(K\) represents the volumes of gross fixed capital in the country; \(L\) is the size of the working population; \(E\) is the amount of energy consumed in the country; \(Y\) represents the gross domestic product of the country; \(Trade\) is the level of the country’s economy openness; \(KOF\) is the globalization index; \(U\) is the share of urban population in its total number; \(t = 1 \ldots T\) represents the period of the research; \(\theta_t\) is a normally distributed component of statistical errors, considering statistical noise and the influence of random external factors; \(\mu_t\) is a component that explains the reasons for inefficient energy use; and \(\epsilon\) is the statistical error of the model.

One should note that the proposed methodological tools for assessing energy efficiency gaps in the national economy allow consideration of the random nature of endogenous determinants of energy efficiency gaps, retrospective dynamics of the changes in energy efficiency gaps in Ukraine, and identifying critical bifurcation points.

The following indicators were selected as independent exogenous variables:

- globalization index (\(KOF\));
- level of openness of the economy (\(Trade\));
- level of urbanization (\(U\)).

Before constructing a translogarithmic, stochastic production function, it is necessary to carry out the normalization procedure. In this paper, the logarithmization of all model variables is used for normalization. If the studied variable is negative, the time series is first increased by one, and then logarithmically.

At the next stage, the study checks the following hypothesis (H1): that greenhouse gas emissions linked with energy efficiency gaps and gross domestic product explain economic growth. In addition, the indicators of globalization index, level of openness of the economy, and level of urbanization were taken as explanatory variables. Considering the findings in previous papers [2,11,12,66], the abovementioned variables have influenced economic growth. In addition, the indicators of globalization index, level of openness of the economy, and level of urbanization were taken as explanatory variables. Considering the findings in previous papers [2,11,12,66], the abovementioned variables have influenced economic growth. Thus, using the EKC hypothesis (7), the function for checking the link between economic growth and energy efficiency gaps was developed in (8). In this case, \(Pollution\) was explained by \(GHG\) emissions in kt of \(CO_2\) equivalent, with an output of GDP per capita.

\[Pollution = f(X, X^2, \xi)\]

where \(Pollution\) refers to environmental pollution, \(X\) is the output, and \(\xi\) is the control variable.

\[GHG_t = a_0 + a_1 GDP_t + a_2 GDP_t^2 + a_3 PE_t + a_4 KOF_t + a_5 Trade_t + a_6 U_t + e_t\]  

where \(t\) is the year, \(e_t\) is the error, \(a_0, \ldots, a_6\) represents the regression’s parameters, \(GHG\) represents greenhouse gas emissions in kt of \(CO_2\) equivalent, \(GDP\) is the GDP per capita, \(PE\) is the energy efficiency gap, \(KOF\) is the globalization index, \(Trade\) indicates the level of openness of the economy, and \(U\) is the level of urbanization.

For checking the H1 hypothesis, the ordinary least squares (OLS) method was used. A sample of time series was formed to estimate the energy efficiency gaps. The study’s information base included analytical data from the World Bank, the Swiss Institute of Economics, and the International Energy Agency. The Stata 14 software package for 2002–2019 was used to calculate energy efficiency gaps.
4. Results

Initial data for calculation are in Table 1.

Table 1. Baseline data for estimating energy efficiency gaps in the national economy.

| Year | $L$ | $K$ | $Y$ | $E$ | KOF | Trade | U |
|------|-----|-----|-----|-----|-----|-------|---|
| 2000 | 49.18 $\times 10^6$ | 6139.44 $\times 10^6$ | 31,303.63 $\times 10^6$ | 2721.67 | 59.80 | 119.82 | 67.15 |
| 2001 | 48.64 $\times 10^6$ | 7097.44 $\times 10^6$ | 38,005.62 $\times 10^6$ | 2754.52 | 60.28 | 103.96 | 67.15 |
| 2002 | 48.21 $\times 10^6$ | 7696.26 $\times 10^6$ | 42,382.44 $\times 10^6$ | 2812.98 | 60.04 | 100.69 | 67.29 |
| 2003 | 47.82 $\times 10^6$ | 9793.65 $\times 10^6$ | 50,085.63 $\times 10^6$ | 3026.01 | 61.13 | 107.45 | 67.42 |
| 2004 | 47.44 $\times 10^6$ | 13,897.85 $\times 10^6$ | 64,827.78 $\times 10^6$ | 3032.07 | 62.55 | 113.75 | 67.63 |
| 2005 | 47.11 $\times 10^6$ | 17,898.81 $\times 10^6$ | 86,119.35 $\times 10^6$ | 3032.07 | 63.31 | 97.22 | 67.76 |
| 2006 | 46.78 $\times 10^6$ | 25,096.64 $\times 10^6$ | 107,957.13 $\times 10^6$ | 2936.58 | 65.04 | 91.47 | 67.97 |
| 2007 | 46.50 $\times 10^6$ | 37,215.83 $\times 10^6$ | 142,984.20 $\times 10^6$ | 2995.90 | 67.63 | 90.83 | 68.17 |
| 2008 | 46.27 $\times 10^6$ | 45,003.23 $\times 10^6$ | 179,959.92 $\times 10^6$ | 2910.27 | 70.04 | 96.93 | 68.31 |
| 2009 | 46.04 $\times 10^6$ | 20,404.07 $\times 10^6$ | 116,948.56 $\times 10^6$ | 2487.42 | 71.45 | 89.84 | 68.51 |
| 2010 | 45.86 $\times 10^6$ | 23,190.30 $\times 10^6$ | 136,010.78 $\times 10^6$ | 2887.08 | 71.88 | 98.10 | 68.58 |
| 2011 | 45.72 $\times 10^6$ | 28,810.33 $\times 10^6$ | 162,997.39 $\times 10^6$ | 2768.33 | 74.29 | 106.27 | 68.72 |
| 2012 | 45.58 $\times 10^6$ | 33,405.95 $\times 10^6$ | 176,044.04 $\times 10^6$ | 2686.51 | 74.59 | 104.06 | 68.79 |
| 2013 | 45.49 $\times 10^6$ | 30,899.32 $\times 10^6$ | 183,045.39 $\times 10^6$ | 2552.94 | 74.66 | 95.11 | 68.85 |
| 2014 | 45.26 $\times 10^6$ | 18,891.92 $\times 10^6$ | 133,985.85 $\times 10^6$ | 2335.54 | 75.04 | 100.69 | 68.99 |
| 2015 | 45.17 $\times 10^6$ | 12,301.66 $\times 10^6$ | 90,988.59 $\times 10^6$ | 2591.52 | 76.94 | 107.77 | 69.06 |
| 2016 | 44.99 $\times 10^6$ | 14,392.89 $\times 10^6$ | 93,385.32 $\times 10^6$ | 2565.73 | 76.86 | 105.53 | 69.13 |
| 2017 | 44.81 $\times 10^6$ | 17,703.00 $\times 10^6$ | 112,026.36 $\times 10^6$ | 2540.20 | 76.48 | 103.75 | 69.27 |
| 2018 | 44.63 $\times 10^6$ | 23,097.73 $\times 10^6$ | 130,939.34 $\times 10^6$ | 2514.93 | 75.26 | 99.09 | 69.34 |
| 2019 | 44.37 $\times 10^6$ | 27,708.36 $\times 10^6$ | 153,966.36 $\times 10^6$ | 2489.91 | 74.81 | 90.20 | 69.48 |

$K$: the volume of gross fixed capital in the country; $L$: the size of the working population; $Y$: gross domestic product of the country; $Trade$: the level of country’s economy openness; KOF: globalization index; $U$: the share of urban population in its total number. Source: formed by the author, based on the data from the World Bank, the Swiss Institute of Economics, and the International Energy Agency.

Descriptive baseline statistics for estimating energy efficiency gaps in the national economy and their graphical interpretation are presented in Table 2 and Figure 1.

Table 2. Descriptive statistics and correlation matrix of initial data for estimating energy efficiency gaps in the national economy.

|          | lnL  | lnK  | lnY  | lnE  | lnKOF | lnTrade | lnU  |
|----------|------|------|------|------|-------|---------|------|
| Mean     | 4.61450 | 4.23900 | 23.63100 | 7.90993 | 17.65100 | 4.22500 | 25.32050 |
| Median   | 4.610000 | 4.275000 | 23.70000 | 7.915022 | 17.645000 | 4.230000 | 25.465000 |
| Maximum  | 4.790000 | 4.340000 | 24.530000 | 8.017368 | 17.710000 | 4.240000 | 25.930000 |
| Minimum  | 4.500000 | 4.090000 | 22.540000 | 7.755509 | 17.610000 | 4.210000 | 24.170000 |
| Std. Dev.| 0.077288 | 0.094752 | 0.565554 | 0.079297 | 0.029540 | 0.0110000 | 0.543134 |
| Kurtosis | 2.696913 | 1.600781 | 2.27212 | 1.864484 | 2.173876 | 1.748582 | 2.47774 |
| Jarque-Bera | 0.374328 | 2.385873 | 1.121504 | 1.129823 | 1.215209 | 1.354352 | 2.495637 |
| Probability | 0.829345 | 0.303329 | 0.570780 | 0.56841 | 0.544460 | 0.5808500 | 0.287128 |
| Sum     | 92.2900 | 84.7800 | 472.6200 | 158.1986 | 353.0200 | 84.5000 | 506.4100 |
| Sum Sq. Dev. | 0.113495 | 0.170580 | 6.077180 | 0.119471 | 0.016580 | 0.0023000 | 5.604895 |
Table 2. Cont.

|       | E   | Y   | KOF  | K   | L   | Trade | U   |
|-------|-----|-----|------|-----|-----|-------|-----|
| E     | 1.000 | -0.079 | -0.340 | 0.161 | 0.123 | -0.166 | -0.285 |
| Y     | -0.079 | 1.000 | 0.915 | -0.917 | -0.914 | -0.502 | 0.915 |
| KOF   | -0.340 | 0.915 | 1.000 | 0.697 | -0.956 | -0.400 | 0.991 |
| K     | 0.161 | 0.917 | 0.697 | 1.000 | -0.736 | -0.537 | 0.705 |
| L     | 0.123 | -0.914 | -0.956 | -0.736 | 1.000 | 0.541 | -0.982 |
| Trade | -0.166 | -0.502 | -0.400 | -0.537 | 0.541 | 1.000 | -0.466 |
| U     | -0.285 | 0.915 | 0.991 | 0.705 | -0.982 | -0.466 | 1.000 |

K: the volume of gross fixed capital in the country; L: the size of the working population; E: the amount of energy consumed in the country; Y: gross domestic product of the country; Trade: the level of country’s economy openness; KOF: globalization index; U: the share of urban population, in its total number; e: exponential record of multiplication by ten to the appropriate power; Mean: the average value of the initial data series; Median: the median of the initial data series; Maximum: maximum value of the initial data series; Minimum: minimum value of the initial data series; Std. Dev.: standard deviation; Skewness: the asymmetry measure for the distribution of the original data series; Kurtosis: numerical description of the probability distribution of the actual random variable in the original data series; Jarque—Bera: test statistics to check the normal distribution of the initial data series; Probability: p-value of Jarque—Bera test statistics; Sum Sq. Dev.: the sum of squares of deviations.

At the first stage of the investigation, the descriptive statistics for selected variables was done. The findings in Table 2 confirmed that the average and standard deviation of the variables were in the minimum and maximum interval. Therefore, the highest average value of energy consumed in Ukraine was 3033.18; at the same time, the lowest level was 2334.41. Four variables—the amount of energy consumed, gross domestic product, globalization index, and the share of urban population in its total number—were negatively skewed. Only the volume of gross fixed capital in the country, the size of working population, and the level of country’s economy openness were positively skewed. In particular, the logarithm of all variables was negatively skewed. It allowed the conclusion that the average value could not adequately describe the country’s development. Besides, all variables had a positive level of kurtosis. This means that selected variables are possibly leptokurtic in form. The strong correlations were between parameters K, L, and Y, which proves the core hypothesis of the Cobb–Douglas theory (Table 2). Besides, the tendencies of the globalization process line up with the tendencies of economic development. This was confirmed by the results of the correlation matrix between variables KOF and Y, as seen in Table 2.

A graphical interpretation of descriptive statistics is presented in the Figure 1.

Results from evaluation of parameters \( \alpha_0 \ldots \alpha_9, \beta_0 \ldots \beta_5, \theta_0 \ldots \theta_2 \) from Equations (5) and (6) are in Table 3.

The study results allowed forming of the limit values of the energy efficiency gaps in the national economy. Thus, the range of fluctuations in the magnitude of energy efficiency gaps is from 1 to 0. In this case, if \( PE = 0 \), there are no energy efficiency gaps, and \( PE = 1 \) indicates a critical level of energy efficiency gaps.
Figure 1. Graphical interpretation of initial data for estimating energy efficiency gaps in Ukraine, 2000–2019.
A graphical interpretation of the assessment results of the energy efficiency gaps is shown in Figure 2. The bifurcation points (rapid growth in the level of energy efficiency gaps) were in the years 2010 and 2016.

According to the study results, in Ukraine, the average energy efficiency gaps were 0.12 during the study period. These gaps became the largest in 2009 and 2015, influenced by the global financial crisis and the escalation of military–political conflicts. The growing dynamics of the energy efficiency gaps in Ukraine is due to the excess of the negative effect of increasing exports of primary energy resources and inefficient technologies for their processing over the positive impact of energy-efficient innovations imports.

The findings in Table 4 confirm that in the model, with and without control variables, all indicators have a statistically significant impact on the decrease of GHG, excluding two variables: the level of country’s economy openness and the index of globalization. In addition, $\alpha_1 = 0.00621$ and $\alpha_2 = -0.00741$ for the model with a control variable. For the models without control variables, $\alpha_1 = 0.00571$ and $\alpha_2 = -0.00634$ for model 2; $\alpha_1 = 0.00568$ and $\alpha_2 = 0.016$ for model 3; $\alpha_1 = 0.00556$ and $\alpha_2 = -0.00661$ for model 4; and $\alpha_1 = 0.00543$ and $\alpha_2 = -0.00621$ for model 5. Considering the findings in all models included $\alpha_1 > 0$ and $\alpha_2 < 0$, they confirmed the EKC hypothesis for Ukraine. Thus, increasing of PE by 1% led to an increase of GHG emissions by 1–2%.

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**Table 3.** The results of the assessment of energy efficiency gaps in the national economy.

| Constants of the Model | Constant | Statistical Significance of Constants |
|------------------------|----------|---------------------------------------|
| $\alpha_1$             | 1.366    | 0.048                                 |
| $\alpha_2$             | -2.123   | 0.056                                 |
| $\alpha_3$             | -1.358   | 0.044                                 |
| $\alpha_4$             | 0.081    | 0.023                                 |
| $\alpha_5$             | -0.101   | 0.032                                 |
| $\alpha_6$             | -0.001   | 0.131                                 |
| $\alpha_7$             | -0.022   | 0.236                                 |
| $\alpha_8$             | 0.049    | 0.024                                 |
| $\alpha_9$             | 0.0657   | 0.368                                 |
| $\beta_0$              | -0.051   | 0.048                                 |
| $\beta_1$              | 0.0001   | 0.039                                 |
| $\beta_2$              | -0.003   | 0.024                                 |
| $\beta_3$              | 0.003    | 0.044                                 |
| $\beta_4$              | 0.0004   | 0.126                                 |
| $\beta_5$              | -0.344   | 0.607                                 |
| $\theta_0$             | 1.512    | 0.064                                 |
| $\theta_1$             | 0.332    | 0.156                                 |

Source: calculated by the author.
Table 4. The findings of ordinary least squares (OLS) of the analysis for GHG, GDP, PE, KOF, Trade, and U.

| Variable | Without Control Variable | With Control Variable |
|----------|--------------------------|-----------------------|
|          | 1                        | 2                     | 3                        | 4                        | 5                        |
| GDP      | 0.00621                  | 0.00571               | 0.00568                  | 0.00556                  | 0.00543                  |
|          | (0.000) ***              | (0.000) ***           | (0.000) ***              | (0.000) ***              | (0.000) ***              |
| GDP$^2$  | -0.00741                 | -0.00634              | -0.00624                 | -0.00661                 | -0.00621                 |
|          | (0.000) ***              | (0.000) ***           | (0.000) ***              | (0.000) ***              | (0.000) ***              |
| PE       | —                        | 0.022                 | 0.018                    | 0.019                    | 0.016                    |
|          | —                        | (0.000) ***           | (0.000) ***              | (0.000) ***              | (0.000) ***              |
| U        | —                        | —                     | 0.062                    | 0.046                    | 0.038                    |
|          | —                        | —                     | (0.078) *                | (0.063) *                | (0.051) *                |
| Trade    | —                        | —                     | —                        | -0.350                   | -0.253                   |
|          | —                        | —                     | —                        | 0.516                    | 0.611                    |
| KOF      | —                        | —                     | —                        | —                        | -0.750                   |
| R-squared| 0.610                    | 0.727                 | 0.863                    | 0.876                    | 0.921                    |

*, **, *** represent significance at the 1%, 5%, and 10% levels.

5. Discussion

The study used the SFA and Shepard’s function for estimating energy efficiency gaps. The findings confirmed that the average level of energy efficiency gaps was 0.12, and their values became the largest in 2009 and 2015. Such energy efficiency gaps were the consequences of the global financial crisis and the escalation of military–political conflicts, the negative effect of increasing exports of primary energy resources, and inefficient technologies.

The developed methodology explains the retrospective changes of the energy efficiency gap and helps identify the bifurcation points. The findings allowed an estimation of the efficiency of government regulations for the declining of energy efficiency gaps.

It is noteworthy that contrary to some previous papers [2,4,10,11,13], this study used the endogenous variables of the energy efficiency gap: globalization index, trade openness, and urbanization. In addition, new trends justified the necessity of considering additional determinants that could increase the efficiency of energy consumption [13–25]. In this case, it is possible to analyze the mechanisms and instrument of extending green technologies, spreading biogas technologies among society, and implementing green innovations at companies.

6. Conclusions

Ribera et al. [91] highlighted that energy issues require the use of multi-criteria approaches to identify the options of increasing level of efficiency. Thus, governments should consider all effects (economic, social, financial, cultural, and ecological), due to the development of incentive instruments to minimize energy efficiency gaps. According to the evaluation of practical measures to minimize energy efficiency gaps, it is significant that there was a small number of gaps in 2010 and 2016, when strategies and programs for the energy sector development were ratified. Thus, in 2010 the “State Targeted Economic Program for Energy Efficiency and Development of Energy Production from Renewable Energy Sources and Alternative Fuels for 2010–2020” was implemented. Since 2015, “Sustainable Development Strategy Ukraine—2020”, “National Security Strategy of Ukraine”, and the “National Action Plan on Energy Efficiency until 2020” have also been enacted. One should note that the efficiency of fulfilling the tasks defined by these documents was relatively high at the initial stages. It led to a significant reduction in energy efficiency gaps. The findings confirmed that increasing energy efficiency gaps lead to an increase of environmental pollution. In addition, the increasing of level of urbanization leads to increasing greenhouse gas emissions. In this case, the government should provide a proactive strategy for creating a positive investment climate, to attract additional financial resources.
for extending the green innovations; popularizing the green lifestyle among society; and cultivating energy safety behavior. Thus, in order to decrease energy efficiency gaps, the government should increase energy efficiency by extending and implementing energy efficiency technologies and renewable energies among all sectors. In this case, the EU experience has shown that preferential credits and taxation for green technologies were the most effective incentive instruments. In addition, the Ukrainian government should develop a positive business climate for green investors. Therefore, regulation on providing transparency at all stages of implementing green projects and green investment should be developed at the government level.

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