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Inter-Fuel Substitution, Technical Change, and Carbon Mitigation Potential in Pakistan: Perspectives of Environmental Analysis

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Abstract: Currently, Pakistan is in a stage of urbanization and industrialization, raising its energy demand and supply and carbon dioxide emissions (CO_2Es) due to the excessive use of fossil fuels. In meeting future demand and supply predictions, much emphasis should be given to both energy consumption and the level of inter-factor and inter-fuel substitution possibilities. Specifically, future outcomes for energy demand are more valid when production models contemplate substitution elasticity occurring during the period. To analyze the potential for little reliance on fossil fuels and diminish CO_2Es, the present research has examined the potential for the substitution of energy and non-energy factors (i.e., natural gas, electricity, petroleum, labor, and capital) by using translog productions function over the period between 1986–2019. The ridge regression method is applied to evade the multicollinearity issue in the data. The model analyzes the output elasticity, substitution elasticity, technical progress, and carbon emission scenarios. The results show that the output elasticities are growing, presenting that the contribution of all factors adds to economic growth. The inputs between capital-petroleum, capital-electricity, labor-electricity, capital-natural gas, and natural gas-electricity are extreme substitutes. These substitutes are increasing capital growth and production sizes. The relative difference in technical progress shows a small positive change between 3–7% with convergence evident. Lastly, the investment scenarios under 5% and 10% investment in petroleum reduction are evidence that the CO_2Es would reduce by 7.5 Mt and 10.43 Mt under scenario 1 and 7.0 Mt and 10.9 Mt under scenario 2. The results have broader suggestions for energy-conserving policies, particularly under the China–Pakistan Economic Corridor.

Keywords: energy use; fuel substitution; technical progress; economic growth; CO_2 emissions

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1. Introduction

Many researchers have proposed that energy consumption is imperative for global economic growth (EG). Energy is also imperative for human life, social development, and daily life; however, the related carbon dioxide emissions (CO_2Es) from huge energy consumption have become a matter of interest, particularly as global warming remains [1]. Indeed, the International Energy Agency (IEA) describes that global EG in developed countries averaged 1.7% in 2019, but overall, energy-related CO_2Es fell by 3.2%. The power-sector-related CO_2Es were counted by 36% across the advanced economies, down from a maximum of 42% in 2012. The average CO_2E intensity of electricity generation was reduced by almost 6.5% in 2019 because of the generation of coal-fired plants in advanced economies, which reduced by approximately 15%. The record growth of renewable electricity generation was found by 28% and 12% of wind energy in advanced countries [2]. Moreover, due to industrialization and urbanization, many countries are expected to raise a larger proportion of energy-related CO_2Es [3].

There are '3' noticeable ways through which countries could lessen the share of CO_2Es. First, energy efficiency measures, for example, renewable energy technologies (RETs), high-efficiency furnaces, little energy-consuming machines, and home appliances, can lessen CO_2Es. These technologies can help in reducing CO_2Es and improve society [4]. Gurrib et al. [5] reported that various countries in Europe have started to use blockchain technologies to benefit more from solar energy and reduce their reliance on imported fossil fuels such as oil and natural gas. The following method of mitigation might be via a huge investment in renewable energy, for example, solar, wind, biomass, hydro, geothermal, nuclear, etc. The third approach is that governments could implement tools, for example, carbon taxes, emissions trading systems, storage and carbon capture, etc. [6].

In Asia, Pakistan is the 12th largest energy-consuming country and uses primary energy by 85 million tons of oil equivalent (Mtoe), which has risen by 5% in 2019 [7]. As an alternative for a growing open economy in transition, Pakistan is not an exclusion from this discussion. As given in Figure 1, the level of energy use and CO_2Es have climbed with the growth ratio and EG. It is also evident from Figure 1 that energy utilization and CO_2Es have a direct correlation between increasing and decreasing at the same breakpoints. These breakpoints are observable from 2003 to 2008 and 2009 to 2013. This relationship is not amazing, seeing that Pakistan is the 12th largest energy-consuming economy, with a very low electricity growth of around 11.6% because of a shortage of energy reserves and political administration. In the last decade, Pakistan faced a severe energy disaster and growing CO_2Es, as presented in Figure 1. The reason is that Pakistan is currently reliant on oil by 25.7%, coal by 15.4%, and gas by 35%, of which oil consumption decreased significantly by 22.1%, gas consumption in the domestic sector increased by 9.7%, and coal consumption increased by 9.7% [8]. However, Pakistan contributes 0.8% of worldwide emissions [9]. These situations make Pakistan an appropriate case for analyzing the mitigation potential of inter-fuel substitution and how energy utilization and technical substitution impact EG.

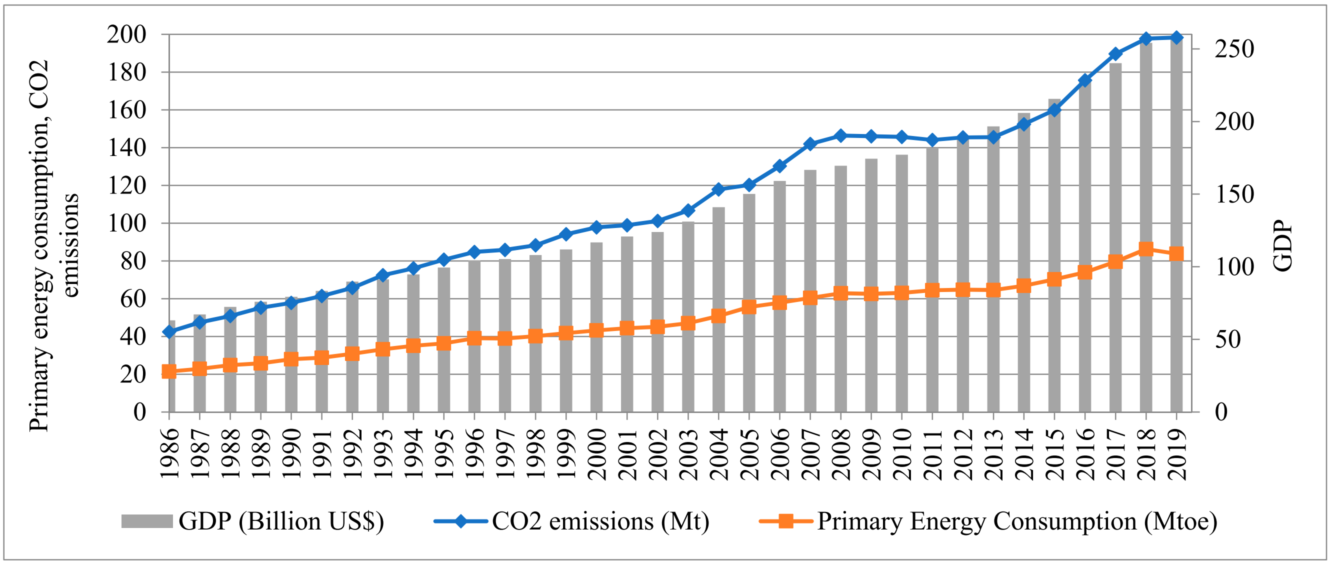

Figure 1. Primary energy consumption, CO_2Es, and gross domestic production in Pakistan (1986–2019). ***Source:*** Pakistan Energy Yearbook [8]; Pakistan Economic Survey [10]; World Bank [7].

As discussed in the next section, the issue concerned with energy use and EG has been considered by applying many techniques, for example, regression analysis, co-integration analysis, bounds testing, decomposition analysis, autoregressive distributive lag model, and bootstrap empirical distribution [11,12]. Many contributions to the literature with various modeling reported mixed findings, which has made literature inclusive and become a matter of concern, particularly seeing the arbitrary nature in which variables are used for these methods. Simply, the commonly applied methods of production analysis as output elasticity, substitution elasticity among the pairs of factors, and technical substitution in the energy economics literature, especially for Pakistan, do not state a certain theoretic association. Moreover, substitutability effects, among the pair of factors that impact due to ecological regulations, costs, and demand variations, are ignored. Due to these motives, different visions on the basis of enhanced modeling would give opportunities.

Hence, we develop a translog production method for energy-economy modeling to investigate the inter-fuel substitution, technological progress, and output elasticity among different energy forms and economic progress to address such issues. However, it also establishes a definite relationship between the selected factors. Afterwards, existing outcomes are employed to measure the substitution possibilities of different kinds of energy and the mitigation potential coming from energy substitution. Paradoxically to these backdrops, the present study supports amplifying the literature, not just in the context of Pakistan's energy policy, but also as it concerns the methodological problems innate in the literature of energy economics. Consequently, the current study motivates us to research input factors, output elasticities, and the pair of substations between factors, technical progress, and mitigation potential using the production model. Thus, the novelty of the current research has produced a gap between the prior research.

Conducting this research for Pakistan will put forward a very imperative contribution, particularly in the context of the energy economy. (1) The dominance of oil, natural gas, and petroleum products in the energy mix must be the main matter, and seeing the energy demand and factor inputs, there is an obvious sign that the demand for these inputs will rise as the economy of the country develops over future [13]. The present study's consequences can be used to enable future predictions that will equate the energy demand–supply inputs that are not only reliant on overall energy use but classified into clean energy, electricity, natural gas, and petroleum products. (2) Familiarity with which kind of energy is close to substitution, analysis of their relative differences in technical progress over time will give helpful insights on which sources of energy should Pakistan prioritize for the expansion of renewable energy and also to be definite of the achievement of any energy transformation policy adapted to the up-gradation renewable energy and control over CO_2Es. (3) The applicability of the energy-oriented translog production model for Pakistan not only limits aggregation bias, but also helps as an imperative basis for various sectors' energy planning and forecasting. Moreover, with the rising demand for energy inputs, as industrialization and urbanization increase or expand, forecasts must be made to compare this demand with the required supply. These forecasts are not only based on the tendency of energy use but also on the degree of inter-factor, inter-fuel substitution, and technical advancements happening in the future. Simply, for future energy, employing production methods can be more authentic if the output elasticities and substitution elasticities are deliberated. Furthermore, controlling CO_2Es in Pakistan seems to propose a need for the utilization of renewable resources, which means that policy-makers see which resources are more substitutable. This is a major concern. Finally, few studies for developed and developing countries have been seen, for example, China, United States, Europe, Africa, and Pakistan, such as [14–17]; to the best of our understanding, there has been no relevant direct study which estimated the inter-factor and inter-fuel substitution, technical progress (among the energy and non-energy factors), and energy-capital investment scenarios, especially for Pakistan. Consequently, only a few studies used old data on electricity, renewable electricity, fossil fuels, and gas for various sectors or regions; therefore, this study is useful for policy-makers to establish whether available clean and fossil fuel resources could be utilized as a substitute. Thus, this study provides a helpful insight into the literature and will benefit in covering the literature gap that subsists in Pakistan.

The major objective is to analyze differences in technological progress and a factor's substitutability, energy consumption, and economic growth. Firstly, the research analyzes the mechanisms of these effects using the translog production function. Secondly, technological progress and economic progress (output) would affect each other (for example, the biased technical progress), and this action has also influenced CO_2 emissions and the economy (see Figure 2).

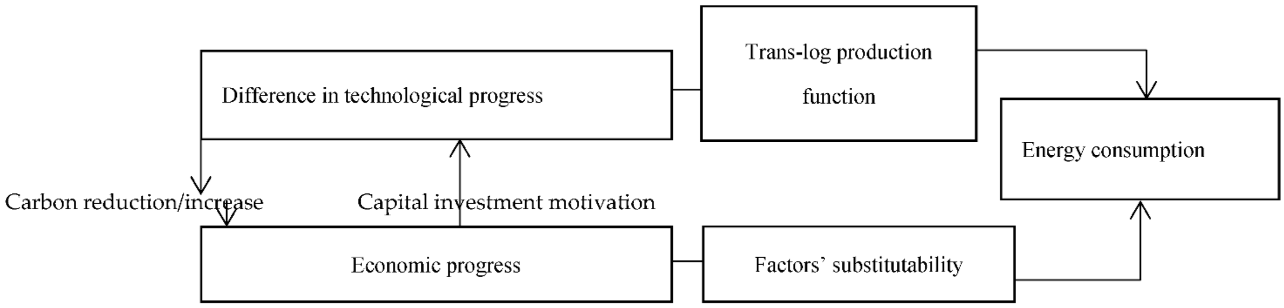

Figure 2. Logical framework of this study.

Further study is arranged as: Section 2 provides the literature review and discusses how the key issues have been addressed. Section 3 presents the data information and their sources. Section 4 introduces the methods and estimation of different variables. Section 5 discusses the empirical outcomes and their description, and Section 6 gives the conclusion and policy recommendations.

2. Literature Review

Two major aspects of literature are important for the debate; research on Energy Consumption (EC) and Economic Growth (EG), and contributions supporting the elasticity of energy substitution. Overall, the literature on the EC and EG relationship is wide, with numerous studies of advanced and emerging nations. Various techniques have been employed in a current analysis by Omri [11] related to EC and EG (i.e., ECM, ARDL bounds, VAR, Granger causality, Causality analysis, Sim's method, Toda-Yamamoto, and Bootstrap distribution) in the literature. Numerous modeling techniques coupled with various substitutive variables for EC have provided mixed outcomes, as revealed in the past. Thus, a summary of the related studies based on various outcomes is provided. At the same time, interested researchers referred to Omri [11] because of multiple supports using multiple methods in the context of two aspect relationships. In his study, Omri indicates that 29% of studies are in favor of the growth hypothesis, and most of the studies applied co-integration and error correction methods. It is found that some studies support the hypothesis, for example, Menyah and Wolde-Rufael [18] on the United States (US); Siddiqui [19] on Pakistan; Zahid [20] on five South Asian countries; Shahbaz et al. [21], Komal and Abbas [22], Ahmed et al. [23], Zhang et al. [24], Raza and Shah [25] on Pakistan; and Lin and Wesseh [26] on South Africa. They emphasize that EC and EG are the imperative influences in the production process, which means that energy plays an imperative part in the EG. Consequently, the conservation of energy policies has a negative impact on EG.

Conflicting to the development hypothesis, only 27% of studies help the feedback hypothesis; for example, Payne and Taylor [27], Sari et al. [28], Payne [29], and Yildirim et al. [14] determine that there is two-way causation between EC and EG. This proves that both (EC and EG) are correlated and might help to complement one another. Additionally, the outcomes show that energy resources (i.e., coal, oil, gas, and renewable) are the long-run forcing variables that are producing employment and production. Moreover, only 23% of the literature supported the conservation hypothesis and concluded that there is a unidirectional causality between EG and EC [15], which clears that the rise in EG raises the EC. Simply, it can be said that the country's economy and infrastructure increase the EC; however, negligence of domestic resources could also produce inadequacy in EC. Finally, only 21% of EC and EG literature have shown a neutral association between EC and EG, which infers that a country carries out plans to save energy, thereby lessening CO_2Es without a negative influence on EG, for example, Altinay and Karagol [30], Jobert and Karanfil [31], Halicioglu [32] for Turkey; Payne and Taylor [27], and Yildirim et al. [14] for the US. They concluded that there is no causal association between the EC and EG.

In connection with the energy and factor substitution literature, the translog production or cost function has been broadly employed because of its flexibility, ease of use, and adaptability. Thus, numerous studies have been done on this topic (For example, Berndt and Wood [33]; Shankar and Pacauri [34]; Fuss [35], and Prywes [36]. They estimated that there is a substitution possibility between energy and capital inputs. Moreover, energy fuels could be substituted at a lower level or higher level of substitution possibilities. In addition, many of the latest studies analyzed the substitutability among various energy and non-energy elements at sectorial, national, and regional levels. For this, few studies supported capital and energy substitutability, for example, Lin and Wesseh [37] for the chemical sector of China Lin and Xie [38] for China's transport industry, and Lin et al. [39] for Ghana's energy economy. Furthermore, to support the substitution possibility between capital and energy inputs, Raza et al. [16] applied the translog production method and examined the substitution influence on economic progress and the chemical sector in Pakistan. They further proved that there is a large substitution possibility among capital and energy input factors. Similarly, Lin et al. [39] and Lin and Atsagli [15] used the translog production model to inspect the substitution possibilities among energy and non-energy factors for Ghana and Nigeria. Actually, these studies found conclusions linked to capital, labor, and literature. In addition, Stern [40] investigated empirical studies in the capital and energy hypothesis results based on 47 countries. Stern decided that changes in the consequences of different studies on the substitution of energy and capital inputs are an outcome of the differences in statistics set applied in different research (i.e., time series, cross-sectional, pooled data, etc.), methods applied in different studies (i.e., national, regional, and sectorial), data sample, and economic situation of the country on which research is done. Similarly, Smyth and Narayan [41] claimed that Stern's work was before 1990 and again proved the mixed results.

Thus, due to huge pressure on countries to bind their energy selections and make a conversion towards renewable energy sources, it has become compulsory, particularly when only several studies are available, to analyze the impact of energy alternatives in lessening energy poverty, reducing CO_2Es, and encouraging EG. Additionally, the provided mixed results in the past studies draw more profound visions from more robust techniques. These attempts would give value in concluding the causation between EC and EG and suggest openings for coming research and framework.

Finally, the literature based on the US, Europe, Africa, China, Pakistan, and other mixed countries found an exact and mixed relationship that proves that countries rely on EC. Remarkably, very little research on all energy factors, their substitution, and technical progress have been conducted in Pakistan, notwithstanding the common consensus that Pakistan needs to control huge fossil fuels and imported oil, coal, gas, mitigate CO_2Es, and switch towards cleaner fuels. As per the author's understanding, only two published research for Pakistan are found that analyzed the potential for energy (i.e., fossil fuels and gas) and non-energy factors (i.e., capital and labor) [16,42]. Both studies ignore the output elasticity and substitutability among electricity, petroleum, and gas, which is very important to debate. Therefore, the current research contributes to this literature by seeing other factors as well as the country's energy and environmental influence over the future. Consequently, substitutions between different inputs used in the current research have never been applied. Additionally, the association between labor, capital, electricity, gas, petroleum, and the mitigation potential of substitution, among all the inputs, has never been investigated in Pakistan. Thus, existing research gives novel insights into the literature.

3. The Data

Annual data on electricity consumption, petroleum, and natural gas are utilized to indicate energy inputs. Aggregate output, gross capital formation, and labor designate '3′ other non-energy inputs used in the present research. The sample period of all factors starts from 1986–2019 from the country's available sources. All the influences used in this research are set appropriately to verify the robustness of the results. For example, to satisfy the production model's conditions, overall, the time series in the current research has been standardized by natural logarithm (ln). For this, we divided all the time series using their sample means [42]. All the data information is as follows: (1) data related to energy, including electricity, petroleum, and natural gas is collected from Pakistan Energy Yearbook [8]. (2) CO_2Es statistics are composed by the World Bank [7]. (3) Data based on labor, capital, and output are gathered from the World Bank [7] and Pakistan Economic Survey [10]. The capital stock information is derived from the statistics of the gross capital formation using the following relationship.

$$K_t = I_t + (1 - \delta_t) \times K_{t-1} \tag{1}$$

where K_t is capital stock, K_{t-1} is the capital stock of the last year, I_t is the current capital investment, and δ_t is the depreciation rate of capital. Seeing Pakistan's investment characteristics and literature, a 5% depreciation rate (A 5% capital depreciation rate is estimated by taking the average value of Pakistan's capital depreciation in 2016. The state bank of Pakistan considered the depreciation rate by 6% [43], and the Pakistan Economic Survey [10] examined this rate as 5% for Pakistan, which has been considered in Pakistan literature, for instance, Lin and Ahmad [42]; Lin and Raza [44]. Moreover, a similar rate is in the practice of some other emerging countries, for instance, Wesseh and Lin [12] for Egypt and Lin and Atsagli [15] for Nigeria) is considered. The equation used to measure the capital stock is provided in Equation (2).

$$K_0 = \frac{I_t}{(g + \delta)} \tag{2}$$

where K_0 and I_0 are the initial capital stock and capital investments. 'g' is the average growth rate of capital investment from 1986–2019.

4. Model Framework and Data Estimations

4.1. Framework

The translog production function is a 2nd-order Taylor series estimation showing the association among different energy and non-energy factors. As per principal duality, past studies investigating substitutability have either applied the cost function or translog production functions. The duality hypothesis suggests to the knowledge that any problem of an important optimization could be defined either as minimizing or maximizing, and the issue is associated with a proper limitation; therefore, the primal could be a minimum or maximum problem. Moreover, the translog production function has some advantages: (1) it measures the factors' substitutability and their elasticities; (2) it imitates the boundary of independent variables; (3) the number of production factors has no limitations. The translog cost function is also beneficial, and measures, including conditional demand factors, are linear and have fewer unknown limitations. Because of the unavailability of price data, we could not use the translog cost function. In addition, this method can utilize two input variables, including linear and nonlinear quadratic terms, and can be estimated using the second-order Taylor series suggested by Christensen et al. [45]. Capital, labor, electricity, petroleum, and gas are used as input factors to establish a translog production function for Pakistan that can be estimated as below.

$$\ln Y_t = \ln \alpha_0 + \sum_a \alpha_a \ln X_{at} + \frac{1}{2} \sum_a \sum_b \alpha_{ab} \ln X_{at} \ln X_{bt} \tag{3}$$

where Y_t indicates the output, α_0 defines the state of technical knowledge, X_{at} and X_{bt} signify the inputs between inputs a and b in time t. α_b and α_{ab} show the technically determined parameters. This is reliant on two times differentiation of the translog production method. As per Pavelescu [46], using the present functional form allows one to evade the imposition of assumptions, for instance, perfect competition or perfect substitution among the inputs. For the country's energy inputs, the translog production function can be described in Equation (4):

$$\begin{gathered}\ln Y_t = \alpha_0 + \alpha_K \ln K_t + \alpha_L \ln L_t + \alpha_{EC} \ln EC_t + \alpha_{NG} \ln NG_t + \alpha_{PT} \ln PT_t + \alpha_{EC} \ln EC_t + \\ \alpha_{K.L} \ln K_t \cdot \ln L_t + \alpha_{K.EC} \ln K_t \cdot \ln EC_t + \alpha_{K.NG} \ln K_t \cdot \ln NG_t + \alpha_{K.PT} \ln K_t \cdot \ln PT_t + \\ \alpha_{L.EC} \ln L_t \cdot \ln EC_t + \alpha_{L.NG} \ln L_t \cdot \ln NG_t + \alpha_{L.PT} \ln L_t \cdot \ln PT_t + \alpha_{EC.NG} \ln EC_t \cdot \ln NG_t + \\ \alpha_{EC.PT} \ln EC_t . \ln PT + \alpha_{NG.PT} \ln NG_t \cdot \ln PT_t + \alpha_{K.K} (\ln K)^2 + \alpha_{L.L} (\ln L)^2 + \alpha_{EC.EC} (\ln EC)^2 + \\ \alpha_{NG.NG} (\ln NG)^2 + \alpha_{PT.PT} (\ln PT)^2\end{gathered} \tag{4}$$

where Y_t shows the economic output. K_t, L_t, EE_t, NG_t, and PT_t indicate the capital, labor, electricity, natural gas, and petroleum inputs, respectively. α is the input of the parameters to be estimated while t is the time. For the linear homogenous production approach, the output elasticity (γ_{at}) of the ath input can be assessed by taking the derivate of Equation (4) with respect to each factor as.

Output elasticity for capital, labor, electricity, natural gas and petroleum calculations can be described by Li et al. [47] using the following Equations (5)–(9):

$$\gamma_{Kt} = \left(\frac{d \ln Y_t}{d \ln K_t}\right) = \alpha_K + \alpha_{K.L} \ln L_t + \alpha_{K.EC} \ln EC_t + \alpha_{K.NG} \ln NG_t + \alpha_{K.PT} \ln PT_t + 2\alpha_{K.K} \ln K_t \tag{5}$$

$$\gamma_{Lt} = \left(\frac{d \ln Y_t}{d \ln L_t}\right) = \alpha_L + \alpha_{L.K} \ln K_t + \alpha_{L.EC} \ln EC_t + \alpha_{L.NG} \ln NG_t + \alpha_{L.PT} \ln PT_t + 2\alpha_{L.L} \ln L_t \tag{6}$$

$$\gamma_{ECt} = \left(\frac{d \ln Y_t}{d \ln EC_t}\right) = \alpha_{EC} + \alpha_{K.EC} \ln K_t + \alpha_{L.EC} \ln L_t + \alpha_{EC.NG} \ln NG_t + \alpha_{EC.PT} \ln PT_t + 2\alpha_{EC.EC} \ln EC_t \tag{7}$$

$$\gamma_{NGt} = \left(\frac{d \ln Y_t}{d \ln NG_t}\right) = \alpha_{NG} + \alpha_{K.NG} \ln K_t + \alpha_{L.NG} \ln L_t + \alpha_{EC.NG} \ln EC_t + \alpha_{NG.PT} \ln PT_t + 2\alpha_{NG.NG} \ln NG_t \tag{8}$$

$$\gamma_{PTt} = \left(\frac{d \ln Y_t}{d \ln PT_t}\right) = \alpha_{PT} + \alpha_{K.PT} \ln K_t + \alpha_{L.PT} \ln L_t + \alpha_{EC.PT} \ln EC_t + \alpha_{NG.PT} \ln NG_t + 2\alpha_{PT.PT} \ln PT_t \tag{9}$$

After analyzing the output elasticity of each factor, the substitution possibilities among the two input factors are obtained by solving:

$$\phi_{ab} = \frac{\%change\ in \left(\frac{X_{at}}{X_{bt}}\right)}{\%change\ in \left(\frac{P_{jt}}{P_{it}}\right)} \tag{10}$$

For the substitution elasticity between input factors, we set Equation (11).

$$\phi_{ab} = \frac{\%change\ in \left(\frac{X_{at}}{X_{bt}}\right)}{\%change\ in \left(\frac{MP_{bt}}{MP_{at}}\right)} = \frac{d\left(\frac{X_{at}}{X_{bt}}\right)}{d\left(\frac{MP_{bt}}{MP_{at}}\right)} \times \left(\frac{\left(\frac{MP_{bt}}{MP_{at}}\right)}{\left(\frac{X_{at}}{X_{bt}}\right)}\right) \tag{11}$$

where MP_{at} and MP_{bt} are the marginal productivity of input factors a and b. Thus, the substitutability between input factors can be calculated from Equation (11). Moreover, a detailed description of the full derivation of the substitution elasticity formula is mentioned in [16].

$$\phi_{ab} = \left[1 + \frac{-\alpha_{ab} + \left(\frac{\gamma_a}{\gamma_b}\right) \times \alpha_{ab}}{-\gamma_a + \gamma_b}\right]^{-1} \tag{12}$$

where '*ab*' is the pair of two factors that shows the elasticity of substitution. Hence, the substitutability between petroleum-electricity, petroleum-natural gas, natural gas-electricity, capital-labor, capital-electricity, capital-natural gas, capital-petroleum, labor-electricity, labor-natural gas, and labor-petroleum can be obtained using Equation (12). It can be seen that 'ab' is called the pairs of each factor, for example, in the present study, $\varnothing_{PT.EC}$, $\varnothing_{PT.NG}$,

$\varnothing_{NG.EC}$, $\varnothing_{K.L}$, $\varnothing_{K.EC}$, $\varnothing_{K.NG}$, $\varnothing_{K.PT}$, $\varnothing_{L.EC}$, $\varnothing_{L.NG}$, and $\varnothing_{L.PT}$ show their substitutability between labor, capital, electricity, petroleum, and natural gas.

4.2. Estimation Technique

As per data information and the existence of interaction terms in the models, it looks like a multicollinearity issue. A suitable modeling technique (ridge regression) is necessary to adapt to evade this issue. The advantages of employing Ridge regression are: (a) it is a technique for investigating multiple regression data which suffers from multicollinearity. (b) With the multicollinearity issue, the least square measures are unbiased with higher variances and away from true values. Thus, this method is useful to check the exact value without bias. (c) It reduces the standard error. (d) Provide consistent outcomes. (e) It is the most suitable econometric method since coefficient measures for multiple linear regression methods depend greatly on the model terms' independence [48]. Moreover, in our situation, the ridge trace represents the coefficient measures employing various standards of the ridge parameter; for instance, k is the ridge parameter in the perspective of our study. In many cases, i.e., [49,50], the coefficient measures significantly variate as the k-value goes away from zero. In that case, the coefficient will steady at a specific value of k, which is the exact value as per present ridge outcomes. To test the influence of omitting the translog components for energy, non-energy, and the substitutability among these factors, these variables were made to substitute factors in the model and re-estimated. As shown in Figure 3, the ridge plot of various translog components between energy and non-energy factors attains stability at a significant level of ridge parameter suggesting the weak predictive value of variables. The ridge technique was proposed by Hoerl and Kennard [49,51], which is robust to resolve multicollinearity issues in the model. The optimum value of the ridge parameter (k) is achieved by the ridge trace method, which comes through the threshold that starts from zero to one. For instance, the ridge estimator can be found by calculating $\left(\acute{X}X + kI\right)\hat{\beta} = h$ gives $\hat{\beta} = \left(\acute{X}X + kI\right)^{-1}h$ where $h = \acute{X}Y$, k is the ridge parameter which is $k \geq 0$. The k-value can assure at any level. If the numeric is optimistic but lesser, it means the issue enhances and reduces the σ^2. I demonstrate the identity matrix (i.e., $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$). Since the methods are appropriately provided in the literature, such as the recent method application, interested researchers refer to Wesseh and Lin [12].

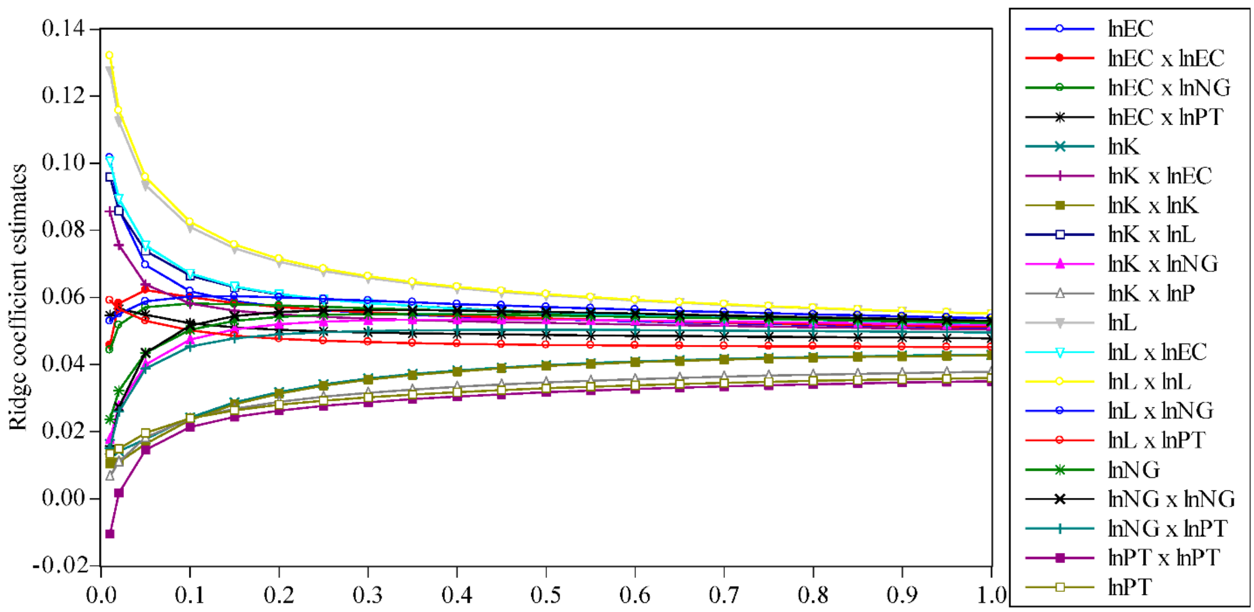

Figure 3. Ridge trace plot based on k values starts from [0.0–1.0].

5. Empirical Results and Discussion

5.1. Empirical Results

5.1.1. Stationarity Analysis, Ridge Trace and Ridge Regression

As per Kmenta [52], the correlation analysis approves the presence of multicollinearity problems in the model. For brevity, the correlation consequences are not provided to show the significant level of multicollinearity. Current outcomes are not astonishing because of the existence of square terms and interactions in the models. As a result, the suitability of ridge regression as an approximation method for this model is defensible. Thus, we estimated the data stationarity, which presents that the total variables utilized in the model are stationary. In addition, Variance Inflation Factor (VIF) value is not supportive because of the higher value (which is more than 10), which shows the high multicollinearity problem in the model. The related outcomes are presented in Table 1, which proposes that all normalized variables in the model are stationary. Therefore, the ridge regression should generate consistent results.

Table 1. Stationarity investigation (normalized variables).

Variables	Augmented Dickey–Fuller	Phillips–Perron	VIF
Economic growth	0.0996 **	0.0961 **	4,524,439
Electricity	0.0012 *	0.0012 *	16,347,136
Natural gas	0.0078 *	0.0094 *	5,885,751
Petroleum	0.0135 *	0.0169	3,538,448

*, ** indicates the stationary at the 1% and 10% significance levels.

Analyzing the ridge regression, it is necessary to control an optimum value for the k parameter; therefore, we approved the ridge trace plot method provided in Figure 3. After analyzing Figure 2, we approved 0.65 as the ridge parameter (k = 0.65). Based on the parametric estimated value, the ridge regression outcomes are presented in Table 2. The outcomes in Table 2 show that all the coefficients are significant, suggesting a reasonable specification. Additionally, the indication of all the coefficients is in line with the economic theory. The VIF values of each element are lower than 10, suggesting that the k-value is suitable. Furthermore, Table 2 presents that the diagnostic estimations performed on the model show significant results. All the factors, such as lnL, lnK, lnEC, lnNG, lnPT, and their multiple measured coefficients show significant outcomes, which propose a sensible specification. It may be viewed that capital, labor, and energy significantly influence Pakistan's economy. Particularly, a unit rise in capital and labor increases the economy by 4.13% and 5.83%, respectively. Interestingly, unit growth in electricity, gas and petroleum increases the economic growth significantly by 5.25%, 5.40%, and 3.42%. These outcomes are consistent with respect to positive results [53]. In particular, the economic insight of significant impact means that energy and non-energy factors (particularly electricity and natural gas) squared strengthens the economic growth by 5.27 and 5.48%, respectively. Consequently, positive and significant values suggest that appropriate investment in renewable energy (i.e., solar, wind, bagasse, biogas, and hydro) will boost Pakistan's economy in future [54]. Moreover, it can be noted that the measures for renewables are added to the electricity because its contribution has just started after 2015; hence, it is significant. As our discussion is based on Pakistan's key driving parameters to estimate the applicability of the model description. Thus, the ridge regression-based table presents that all the parameters contribute positively to Pakistan's economy. Current outcomes are the true picture of Pakistan's economy, which is consistent with [55]. Pakistan is still reliant on imported fuels by 45.57% [8], which is majorly linked to electricity generation. This has impacted the foreign reserves without directly influencing the output (economy) of the oil, coal, gas, and electricity, which play a key role in raising output. Therefore, the substitutability among various factors could be optimum if domestic and technical enhancements are considered. Diagnostic results of the coefficient of determination (R^2) clear that in almost 99% of explanatory variables as directed by the Adjusted R^2 value and Durbin-Watson value (1.63) nearer to 2, which infers that the model did not suffer from serial correlation.

Table 2. Outcomes of ridge regression estimate when k = 0.65.

Variables	Coefficient	Standard Error	t-Statistics	*p*-Value	VIF
lnK	0.0413	0.0309	1.3384	0.0983	0.0793
lnL	0.0583	0.0260	2.2447	0.0184	0.0299
lnEC	0.0525	0.0274	1.9182	0.0351	0.0279
lnNG	0.0540	0.0270	2.0010	0.0299	0.0508
lnPT	0.0342	0.0293	1.1671	0.0106	0.0963
lnK.L	0.0543	0.0269	2.0177	0.0290	0.0131
lnK.EC	0.0516	0.0276	1.8691	0.0386	0.0164
lnK.NG	0.0529	0.0273	1.9402	0.0337	0.0349
lnK.PT	0.0306	0.0237	1.2905	0.1061	0.0600
lnL.EC	0.0542	0.0269	2.0122	0.0293	0.0097
lnL.NG	0.0559	0.0265	2.1076	0.0243	0.0287
lnL.PT	0.0455	0.0294	1.5477	0.0691	0.0353
lnEC.NG	0.0544	0.0269	2.0233	0.0287	0.0160
lnEC.PT	0.0484	0.0285	1.6980	0.0529	0.0113
lnNG.PT	0.0502	0.0280	1.7936	0.0444	0.0085
lnK.K	0.0410	0.0310	1.3238	0.1006	0.0834
lnL.L	0.0586	0.0259	2.2621	0.0178	0.0356
lnEC.EC	0.0527	0.0273	1.9292	0.0344	0.0246
lnNG.NG	0.0548	0.0268	2.0457	0.0274	0.0489
lnPT.PT	0.0331	0.0231	1.4335	0.0775	0.0955
Model diagnostics					
Ridge parameter K	0.65				
R-square	0.9961				
Durbin-Watson	1.6386				
F-statistics	232.526				

5.1.2. Output Elasticity and Elasticity of Substitution

As per the preceding analysis, the translog production function is an appropriate model and is employed at sectorial, regional, and national levels. We estimate five output elasticities (i.e., K, L, EC, NG, PT) and ten pairs of substitution elasticities (i.e., PT.EC, PT.NG, NG.EC, K.L, K.EC, K.NG, K.PT, L.EC, L.NG, and L.PT), as shown in Table 3. From Table 3, we can understand that all five inputs have positive output elasticity, with 'L' showing the maximum influence. This shows there is a need for operative and skilled labor policies. A rising trend of all input factors proves a sign of Pakistan's economic growth (EG) over the period. All five factors present a time-to-time rise with a moderate growth rate, which is an obvious picture of rising returns to scale. Petroleum is the only factor that was found to be optimistic but lower than one on average; all the variables in the statistics were found to be close to '1' or above '1'. Output elasticities of labor, capital, electricity, and natural gas pay devotion to the present outputs' degree of responsiveness to the Pakistan economy for a unit change in the present inputs and imitate the need for actual and effective policies on the given inputs. Thus, given outcomes in Table 3 have given way to the analysis of the substitutability for pair of input factors, and the outcomes are provided in Table 4.

Table 3. Output elasticities among alternative inputs from 1986–2019.

Year	γ_{Kt}	γ_{Lt}	γ_{ECt}	γ_{NGt}	γ_{PTt}
1986	1.1368	1.1490	0.9074	1.0113	0.7433
1987	1.1491	1.1677	0.9271	1.0278	0.7588
1988	1.1579	1.1807	0.9468	1.0419	0.7721
1989	1.1713	1.1964	0.9633	1.0584	0.7849
1990	1.1861	1.2162	0.9841	1.0810	0.8020
1991	1.1984	1.2282	0.9987	1.0951	0.8107
1992	1.2136	1.2465	1.0188	1.1142	0.8269
1993	1.2260	1.2627	1.0376	1.1342	0.8423
1994	1.2308	1.2724	1.0461	1.1444	0.8505
1995	1.2401	1.2834	1.0596	1.1581	0.8609
1996	1.2545	1.3039	1.0800	1.1812	0.8790
1997	1.2531	1.3050	1.0791	1.1775	0.8772
1998	1.2641	1.3179	1.0914	1.1933	0.8869
1999	1.2581	1.3193	1.0890	1.1941	0.8882
2000	1.2712	1.3357	1.1050	1.2123	0.9011
2001	1.2783	1.3426	1.1130	1.2177	0.9049
2002	1.2814	1.3468	1.1171	1.2228	0.9066
2003	1.2940	1.3595	1.1287	1.2362	0.9146
2004	1.3118	1.3795	1.1501	1.2592	0.9304
2005	1.3342	1.4027	1.1746	1.2889	0.9500
2006	1.3585	1.4220	1.1965	1.3136	0.9630
2007	1.3712	1.4350	1.2108	1.3299	0.9723
2008	1.3808	1.4495	1.2237	1.3471	0.9853
2009	1.3785	1.4480	1.2172	1.3445	0.9804
2010	1.3800	1.4539	1.2234	1.3506	0.9847
2011	1.3769	1.4563	1.2260	1.3507	0.9872
2012	1.3832	1.4655	1.2325	1.3606	0.9940
2013	1.3870	1.4729	1.2376	1.3659	0.9995
2014	1.3908	1.4793	1.2468	1.3671	1.0050
2015	1.4041	1.4955	1.2611	1.3790	1.0175
2016	1.4130	1.5112	1.2783	1.3934	1.0338
2017	1.4294	1.5310	1.2994	1.4172	1.0519
2018	1.4436	1.5472	1.3199	1.4314	1.0665
2019	1.4380	1.5420	1.3140	1.4261	1.0593
Average	**1.3013**	**1.3625**	**1.1324**	**1.2419**	**0.9174**

Table 4 clears that all input pairs during the time interval seemed to be positive and near unity, proposing that all the pairs are substitutes. The substitution degree found between capital-petroleum and capital-electricity is the maximum imperative to the Pakistan economy. The outcome is reliable with the results of Raza et al. [16] on Pakistan and Lin and Long [56] on China. The outcome indicates that Pakistan has the potential to invest capital using clean energy resources, and Pakistan has the ability to switch from fossil fuel to technical equipment in increasing renewable energy resources. Simply, by increasing the capital, Pakistan will also save considerable energy and imported fuel and mitigate the CO_2E process. For example, Pakistan has 3000–3300 sunshine hours per year (including 6–7 sun hours in one day), coal reserves of 185 billion tons, natural gas reserves of 19 trillion cubic feet, and $33.8 billion investment in renewable energy investment under China–Pakistan Economic Corridor (CPEC) [25,54,57]. Pakistan can utilize these potentials in growing energy security, and reducing imported fuel and energy costs. In addition, clean coal technologies, RET_S, and the country's controlled policies, i.e., China Pakistan Economic Corridor, One Belt One Road, and renewable energy visions 2025–2035, can mitigate a huge share of CO_2Es and enhance economic development [58]. They analyzed that inexpert labor reduces Pakistan's industrial value, even they increased energy consumption. For instance, enormous energy demand, population, insufficient energy production, technical causalities, limited supply, high costs, and cyclical cuts in energy are the key impacting factors on energy security and economic progress [10].

Table 4. Elasticity of substitution of alternative from 1986–2019.

Year	$\varnothing_{K.L}$	$\varnothing_{K.EC}$	$\varnothing_{K.NG}$	$\varnothing_{K.PT}$	$\varnothing_{L.EC}$	$\varnothing_{L.NG}$	$\varnothing_{L.PT}$	$\varnothing_{PT.EC}$	$\varnothing_{PT.NG}$	$\varnothing_{NG.EC}$
1986	1.0318	1.4220	1.1858	1.4705	1.1938	1.1918	1.0643	0.8293	0.7435	1.0286
1987	1.0238	1.3882	1.1745	1.4450	1.1851	1.1832	1.0599	0.8285	0.7464	1.0225
1988	1.0187	1.3489	1.1623	1.4207	1.1697	1.1677	1.0538	0.8254	0.7489	1.0143
1989	1.0163	1.3327	1.1542	1.4090	1.1633	1.1614	1.0507	0.8246	0.7494	1.0125
1990	1.0108	1.3092	1.1378	1.3880	1.1560	1.1541	1.0458	0.8249	0.7497	1.0123
1991	1.0115	1.2975	1.1327	1.3870	1.1486	1.1468	1.0450	0.8215	0.7482	1.0103
1992	1.0085	1.2791	1.1241	1.3708	1.1412	1.1394	1.0403	0.8214	0.7499	1.0075
1993	1.0046	1.2592	1.1103	1.3528	1.1335	1.1317	1.0352	0.8215	0.7503	1.0070
1994	0.9994	1.2490	1.1015	1.3406	1.1327	1.1310	1.0334	0.8228	0.7508	1.0078
1995	0.9980	1.2370	1.0940	1.3311	1.1269	1.1251	1.0302	0.8222	0.7510	1.0068
1996	0.9921	1.2200	1.0803	1.3124	1.1225	1.1207	1.0258	0.8237	0.7517	1.0075
1997	0.9895	1.2193	1.0837	1.3143	1.1247	1.1230	1.0283	0.8226	0.7525	1.0050
1998	0.9880	1.2136	1.0761	1.3099	1.1226	1.1208	1.0273	0.8223	0.7509	1.0071
1999	0.9804	1.2082	1.0674	1.2978	1.1272	1.1255	1.0270	0.8255	0.7514	1.0103
2000	0.9778	1.1993	1.0598	1.2901	1.1242	1.1224	1.0251	0.8254	0.7510	1.0110
2001	0.9784	1.1958	1.0617	1.2927	1.1213	1.1195	1.0259	0.8228	0.7508	1.0079
2002	0.9774	1.1929	1.0589	1.2935	1.1205	1.1187	1.0270	0.8213	0.7493	1.0084
2003	0.9779	1.1919	1.0571	1.2955	1.1192	1.1175	1.0276	0.8200	0.7479	1.0090
2004	0.9767	1.1814	1.0498	1.2889	1.1136	1.1118	1.0253	0.8186	0.7470	1.0087
2005	0.9770	1.1730	1.0402	1.2817	1.1077	1.1060	1.0217	0.8184	0.7454	1.0111
2006	0.9827	1.1721	1.0388	1.2900	1.1013	1.0996	1.0217	0.8143	0.7418	1.0116
2007	0.9830	1.1670	1.0343	1.2894	1.0977	1.0960	1.0213	0.8125	0.7401	1.0121
2008	0.9790	1.1600	1.0258	1.2778	1.0970	1.0954	1.0185	0.8146	0.7403	1.0146
2009	0.9782	1.1671	1.0263	1.2839	1.1026	1.1009	1.0219	0.8150	0.7384	1.0184
2010	0.9744	1.1594	1.0214	1.2779	1.1013	1.0996	1.0217	0.8143	0.7383	1.0177
2011	0.9695	1.1511	1.0181	1.2691	1.1006	1.0990	1.0208	0.8147	0.7399	1.0155
2012	0.9672	1.1495	1.0142	1.2650	1.1020	1.1003	1.0204	0.8160	0.7396	1.0178
2013	0.9643	1.1469	1.0126	1.2599	1.1031	1.1014	1.0199	0.8172	0.7407	1.0174
2014	0.9624	1.1384	1.0153	1.2552	1.0992	1.0976	1.0190	0.8156	0.7437	1.0103
2015	0.9607	1.1348	1.0164	1.2504	1.0985	1.0968	1.0177	0.8163	0.7460	1.0073
2016	0.9557	1.1218	1.0108	1.2340	1.0945	1.0928	1.0130	0.8183	0.7497	1.0039
2017	0.9539	1.1134	1.0035	1.2244	1.0903	1.0886	1.0094	0.8192	0.7500	1.0045
2018	0.9531	1.1035	1.0034	1.2182	1.0839	1.0822	1.0067	0.8176	0.7526	0.9984
2019	0.9525	1.1044	1.0031	1.2227	1.0852	1.0835	1.0095	0.8157	0.7505	0.9993
Average	**0.9846**	**1.2090**	**1.0664**	**1.3091**	**1.1209**	**1.1192**	**1.0283**	**0.8201**	**0.7470**	**1.0107**

5.1.3. Technological Progress

We analyze the relative difference in technical progress by seeing the significance of energy and nonenergy input factors for Pakistan's economic development and the substitution potential between pairs of factors. For this, we use the aggregate translog production function by combining output elasticities and the assessed coefficient given in Equation (4). By the changeability over time, the function used for this analysis was suggested by Xie and Hawkes [59] and Wesseh and Lin [12]. The employed function in this research is as follows:

$$TP_{ab} = \frac{\alpha_a}{\gamma_a} - \frac{\alpha_b}{\gamma_b} \quad (13)$$

where TP_{ab} illustrates the difference between the technical progress of 'a' and 'b' inputs. α_a and α_b are the estimated coefficients obtained from Equation(4). γ_a and γ_b are the output state of technical knowledge. According to Equation (12), if TP_{ab} is positive, then the state of technical progress for 'a' is faster than 'b'. If the TP_{ab} is negative, then the state of technical progress for 'b' is quicker than input 'a'. TP_{ab} will remain at the same level if TP_{ab} is zero. The outcomes described in Figure 4 show that all the input pairs are greater than '0', presenting that TP_{ab} among all the factors is largely driven and changes between 3% and 7%. At this level of technical variations, the effort is also carried out to analyze the mitigation potential coming from energy substitution.

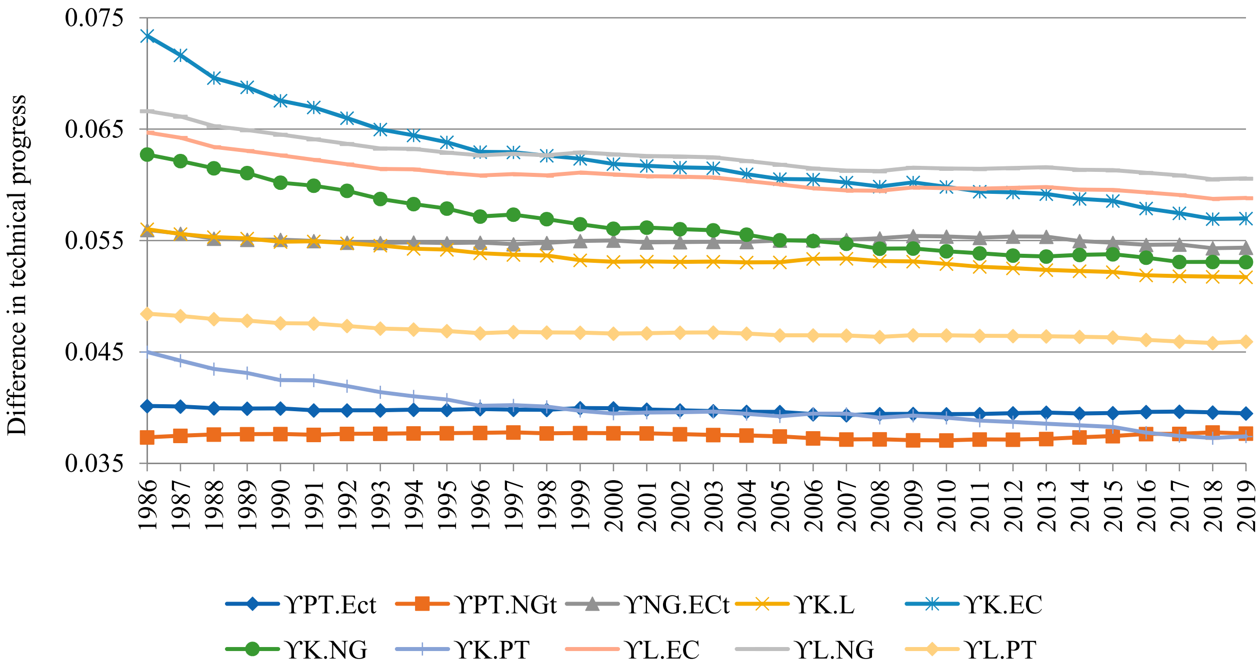

Figure 4. Technical progress among the input pairs of factors from 1986–2019.

5.1.4. Scenario Analysis

One must not forget that Pakistan is also of the countries which are consuming huge amounts of fossil fuel energy in the world; thus, the level of CO_2Es in the country has grown significantly since the year 1986. As a specific case, we analyze how a definite rise in capital investment linked with natural gas would lessen pollution. The scenarios we employed correspond to a change in capital investment which suits the profit and society's better decision. As shown in Figure 1, Pakistan has one of the twelfth highest-energy-consuming countries in Asia-Pacific, reaching 84 Mtoe in 2019. Thus, the level of the country's CO_2Es has increased by more than 198 Mt with a contribution of 0.8% to the world emissions since the year 1986 [9]. Therefore, it becomes necessary to estimate how inter-fuel substitution can be decomposed and then check the impact on Pakistan's CO_2Es. For this, we categorized the impacts of various phases as a result of technological progress (increase/decrease) and identified that the progress of Pakistan's CO_2Es is impacted by the labor, capital, and structure of energy consumption. Our study proves that low-emission energy capital investment can lessen CO_2Es and impact productivity. Following the past studies, for example, Chen et al. [60], the equation for decomposing CO_2Es is as follows:

$$CO_2{}^t = \sum_{i=1}^{34} CO^t{}_{2,i} = \sum_{i=1}^{34} \frac{CO^t{}_{2,i}}{O^t{}_i} \times O^t{}_i \tag{14}$$

where i show the study period and $O^t{}_i$ shows the economic growth due to capital change in time t. Considering the production model, economic development arises from the supply of sources (i.e., capital, labor, and technology), while it can also affect the demand for resources. In order to find out the capital investment relationship with carbon reduction, we employed the decomposition model to obtain Equation (15).

$$CO_2{}^t = \sum_{i=1}^{34} CO^t{}_{2,i} = \sum_{i=1}^{34} \frac{CO^t{}_{2,i}}{O^t{}_i} \times O^t{}_i = \sum_{i=1}^{34} \frac{CO^t{}_{2,i}}{O^t{}_i} \times TFP^t{}_i \times (K_i^t)^{\alpha_i} \times (L_i^t)^{\beta_i} \tag{15}$$

Under the assumption, the scale returns are constant, such as α_i and β_i are constant and equal to one. Thus, the equation can be modified as in Equation (16).

$$CO_2{}^t = \sum_{i=1}^{34} CO^t{}_{2,i} = \sum_{i=1}^{34} \frac{CO^t{}_{2,i}}{O^t{}_i} \times O^t{}_i = \sum_{i=1}^{34} \frac{CO^t{}_{2,i}}{O^t{}_i} \times TFP^t{}_i \times \left(\frac{K_i^t}{L_i^t}\right)^{\alpha_i} \times (L_i^t) \quad (16)$$

where $TFP^t{}_i$ shows the total factor productivity, $K^t{}_i$ is the capital, $L^t{}_i$ is the labor, and α_i is the elasticity of capital elements to output. As linked with the econometric model that can just disclose the association between TP and CO_2Es, the combination of decomposition and production models can better decompose and judge the impacts of various driving forces on CO_2Es, comprising low carbon-emitting fuels and modernization. Moreover, in this method, we can accomplish the net effects of technical change as well as the CO_2E reduction, which could be adjusted to scenarios with the non-linear relationship between energy advancement and CO_2Es. It can be seen that $TFP^t{}_i$ is decomposed by the production function, which is positively associated with output and CO_2E reduction during the specified period, as shown in Table 5. This is because technology and clean resources are key factors determining productivity, where TP outcomes in more production and succeeding CO_2Es [61]. Thus, we employed TFP as production technological changes in Pakistan under the energy and carbon intensity. This has been previously conducted by Yabe [62], as carbon intensity based on Japanese industries.

Table 5. Petroleum reduction and CO_2Es mitigation (Pakistan).

Period	Petroleum Reduction (Mtoe)	CO_2 Emissions Reduction (Mt)
Scenario 1 (Raising natural gas capital investment by 5%)		
2013	18.397695	7.550966
2016	16.321575	10.276881
2019	18.138939	10.435593
Scenario 2 (Raising natural gas capital investment by 10%)		
2013	19.273776	7.910535
2016	17.098793	10.766256
2019	19.002698	10.932526
Scenario 3 (Total factor productivity growth and CO_2 emissions reduction as business as usual)		
2013	0.053567	0.000739
2016	0.053470	0.000772
2019	0.05306	0.000772

As per the past measurement, we investigated that the investment is a huge share of capital in natural gas instead of petroleum products and reduction in CO_2Es using the input capital growth-share by 5% and 10%. For instance, Lin and Long [56] estimated rising energy capital and CO_2E reduction under 5%, 9%, and 15% scenarios for China; Raza et al. [16] analyzed energy conservation and CO_2Es under 5%, 10%, and 15% scenarios for Pakistan; Lin and Raza [44] investigated CO_2Es mitigation scenarios at 5% and 10% level for Pakistan's transport sector in 2020. Thus, as per previous research, it is obvious that capital growth can reduce CO_2Es and save energy. As a current case based on energy and economy, we analyze how a definite rise in capital investment linked to natural gas, such as the substitution between gas and petroleum would lessen CO_2Es. For this, we employed the approach of Wesseh and Lin [12], in which outcomes of substitutability received between natural gas and petroleum are used in various scenarios. These scenarios correspond to a 5% and 10% rise in the natural gas capital to lessen the share of petroleum over the period of 2013, 2016, and 2019. This analysis applies petroleum use and CO_2Es data, as shown in Table 5. As per Table 5, results propose that a 5% and 10% rise in capital investment is associated with petroleum-lessening technologies. This might cause a consistent lessening in petroleum by 18.39, 16.32, and 18.13 Mtoe and 19.27, 17.09 and 19.002 Mtoe for the period 2013, 2016, and 2019, respectively. As a consequence of petroleum use reduction, the CO_2E level under the 5% scenario reduces by 7.55, 10.27, and 10.44 Mt corresponding to the years 2013, 2016, and 2019. Under the 10% investment scenario, a corresponding lessening in CO_2Es occurs by 7.91, 10.76, and 10.93 Mt for the years 2013, 2016, and 2019, respectively. The present outcomes from the various scenarios propose that petroleum substitutability for natural gas can potentially lessen CO_2Es in Pakistan without a negative impact on EG. It must be kept in mind that the type of substitution, in this case, is relative, which means that the successive rise in natural gas consumption as a consequence of lessening in petroleum consumption refers to the amount of petroleum decrease and its support to economic development. In addition, as per Pakistan Economic Survey [63], Pakistan holds 19 trillion cubic feet of proven gas reserves as of 2017, ranking 29th in the world that could be used for energy conservation, imported cost-saving, and a clean environment. Moreover, based on internal benefits (i.e., environmental and economic) and investment linked to technology should be made sure of.

5.2. Discussion

In this part, we examine a few of the major findings of the current research. We start from the influence of EC, NG, and PT on the Pakistan economy to the output elasticity and substitution possibilities without influencing EG. Furthermore, we also considered the relative difference in technological progress among energy and non-energy factor inputs and gave the potential that Pakistan has to mitigate CO_2Es as a consequence of energy substitutability attempts.

Our results suggest that all the output elasticities are elastic, with the labor elasticity showing the maximum degree of responsiveness, followed by the EC, K, NG, and PT, which is evidence of the growing consumption trend of all inputs over the future. It also indicates that Pakistan's output elasticity progress is extremely subtle in raising employment and energy utilization. From the substitutability perspectives, the possibilities between all factors are close or above the unity, which proposes that K-PT, K-EC, K-NG, and L-EC are critically imperative for raising the capital and energy production capacities, energy conservation, energy security, economy, and environmental sustainability in Pakistan. Furthermore, capital, labor, and electricity substitution are important for employment, skilled labor, and energy security. Many benefits could be achieved to ensure capital as a major substitute because of existing energy resources (i.e., coal, gas, solar, wind, bio, and oil) [64]. In addition, substitution from one energy to another (i.e., petroleum-electricity, petroleum-natural gas, and natural gas-electricity) would need some level of technology in which capital could be utilized to upgrade old to new machinery, renewable energy technologies (RETs), and electrical installations. Therefore, this process should be implied in the process for different sectors, policy-makers may be needed to design cost-related policies to decrease capital expenditure. These policies not only reduce taxes and capital expenditure but also help to cut the cost of electricity expenditure for industrialists and consumers. It could also be noted that industrial size and nature of fuel consumption, for example, transportation, and industrial activities, also play an imperative role in regulating structural variations. For example, Lin and Ahmad [42] and Raza et al. [16], for Pakistan's transport and chemical sector, propose that Pakistan's government invest in RETs, substitution from oil to gas, and clean coal technologies should be enhanced. This will not only control contamination but also create opportunities; for example, Pakistan should substitute its capital in the form of RETs and should apply its energy resources within the framework of energy Visions 2025–2035 [65,66].

Conclusively, research outcomes present that the state of TP is input-dependent and lower than 8% at its highest. This also proves the enormous possibilities for lessening CO_2Es that could come from advancements in different energy technologies in Pakistan, particularly those related to petroleum, natural gas, and electricity. These results show evidence that points to the quantity of CO_2Es reduced as a consequence of fuel substitution for gas and electricity. The indication is very clear that if the energy productivity level is increased at the technical level, the higher CO_2Es could be controlled.

6. Conclusions and Policy Recommendations

This research tried to examine the inter-factor and inter-fuel substitution between capital, labor, electricity, natural gas, and petroleum in Pakistan using the log-linear translog production function method. In order to reduce the multicollinearity issue in the data, ridge regression was employed to handle this problem. This technique was used to an annual data of each factor from 1986–2019. The study's outcomes are employed to measure the substitution possibilities of numerous energy resources and compute the CO_2Es' mitigation potential coming from the substitution among the resources. This model does not merely state the elasticity and substitutability, but also provides the interaction among pairs of factors and the level of technical progress among them. Findings based on the model are provided below.

(1) All the output elasticities are showing positive and rising returns to scale. The output elasticities of capital (1.13–1.43), labor (1.14–1.54), electricity (0.90–1.31), natural gas (1.03–1.43), and petroleum (0.74–1.05) are all rising over 1986–2019. The output elasticity of labor (γ_{Lt}) is the only factor with the highest influence, followed by capital, natural gas, electricity, and petroleum. The significant growth presents that country's economy is progressively rising, and the proportion of technology is gently rising. Overall, the optimistic and growing trend of all inputs is a sign of enhancing the economy in the country.

(2) As per the model's substitution elasticity estimation, all the pair of energy and non-energy factors are estimated. The outcomes propose high substitutability between capital-petroleum, capital-electricity, labor-electricity, capital-natural gas, and natural gas-electricity, as well as petroleum-natural gas. This substitution clears that by raising the capital and energy production capacities; Pakistan has the potential to raise its energy security, economy, and environmental sustainability. The clean energy resources and production-controlled policies, including renewable energy vision-2025, vision-2035, CPEC, and INDC can lessen fuel import and significantly impact the economy. Moreover, the huge reserves of Pakistan's coal and gas (28th and 29th in the world) are evidence of greater productivity and labor efficiency. This will benefit energy security, enhance the living standard, reduce costs, and increase employment. Moreover, the substitutability between capital and energy proposes that there is a growth in energy and technology, which will further lessen the subsidies for enhancing capital and labor. This will encourage investors to invest in lower energy-utilizing appliances, conserving energy, and supporting capital growth. Additionally, labor-electricity substitutability proved that the skills of labor and knowledge would grow energy conservation. Consequently, the outcomes of capital, electricity, labor, and natural gas are evident and there are further motivations for capital and labor in Pakistan.

(3) Technical progress (TP_{ab}) is mainly input-driven and looks quite slow-changing between 3% and 7%. This presents that (TP) between inputs factors (see Figure 4) could become efficient contributors to the economic development of Pakistan. Thus, from the future viewpoint, current results provide an optimal trend in TP, which is also consistent with the studies of Pakistan and China. Therefore, enhancing the relative differences in TP of a particular input may control each factor.

(4) Conclusively, there seem to be significant CO_2E mitigation advantages of inter-fuel substitution in Pakistan in the range of 7.5 and 10.43 Mt under scenario 1 and 7.0 and 10.9 Mt under the 10% investment scenario 2. The results further present that employing huge domestic energy resources could benefit living standards and balance

the economy. Thus, based on the results, a few important policies for Pakistan are as follows.

First, energy-saving policies on various kinds of fuel would affect the higher use of kinds of fuel (i.e., petroleum to renewable or natural gas), and this will have no negative impact on the level of economic progress. This is why: Pakistan has abundant domestic energy reserves, for example, 3000–3300 sunshine hours in a year, 28th and 29th world's largest coal and natural mines. As per Visions 2025–2035, Pakistan has dedicated China to enhancing energy using domestic resources, such as coal, solar, wind, bio, and gas. This is because Pakistan comes in the top 25 countries to enhance economic growth, which is increasing its energy accessibility from 60–90% to its population and mitigating pollution by 2025. Simply, policy-makers in Pakistan have the leverage of imposing taxes and a small share of fossils to the huge fuel consumers without a negative impact on the economy.

Second, the commercial and industrial size (based on fossil fuels) should be made smaller. Smaller industries should be brought into the market (based on modern technology) to raise production capacity with lower energy consumption.

Finally, slower TP and biased nature of technical variation suggest that Pakistan has vast productivity for lessening CO_2Es by improving energy proficiency via novelty in different energy technologies, particularly gas, electricity, and petroleum. Overall, this study, based on the production function, provides energy substitution and the TP in enhancing the economic situation of Pakistan. Furthermore, the model has provided vast ecological advantages through substitution possibilities and suggested maximum mitigation potential for the future if technical advancements are implemented using different energy-related techniques.

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Nomenclature

ARDL	Autoregressive distributive lag
CO_2Es	Carbon dioxide emissions
EC	Energy consumption
EG	Economic growth
ECM	Error correction model
IEA	International Energy Agency
k	Ridge parameter
Mtoe	Million tons of oil equivalent
R^2	Coefficient of determination
RETs	Renewable energy technologies
VAR	Vector auto regression
VIF	Variance Inflation Factor
α_0	State of technical knowledge
α	Input of the parameters
α_b, α_{ab}	Technical determinants of parameters a and b

I_t	Capital investment
K_t	Capital stock of current year
K_{t-1}	Capital stock of previous year
MP_{at}, MP_{bt}	Marginal productivity of '*ab*' factors
TP_{ab}	Technical progress between '*ab*' factors
X_{at}, X_{bt}	Inputs of a and b
δ_t	Capital depreciation
γ_{at}, γ_{bt}	Output elasticity of '*ab*' factors
$\varnothing_{ab}$	Substitution elasticity between '*ab*' factors

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