Driving Factors of Natural Gas Consumption in Pakistan based on LMDI approach

Ibrar H Lund[a,*], Faheemullah Shaikh[b], Khanji Harijan[c], Laveet Kumar[c], Rafeeque A. Nizamani[c]

[a] Directorate of Postgraduate Studies, Mehran University of Engineering and Technology Jamshoro, 76062, Sindh, Pakistan
[b] Department of Electrical Engineering, Mehran University of Engineering and Technology, Jamshoro, 76062, Sindh, Pakistan
[c] Department of Mechanical Engineering, Mehran University of Engineering and Technology, Jamshoro, 76062, Sindh, Pakistan

Abstract

Increasing population and depleting natural gas (NG) reserves may cause NG shortage, and it is necessary to balance the supply-demand gap by devising appropriate policies. This paper investigates the relationship between NG consumption and driving factors using the logarithmic mean division index (LMDI) approach. The following three elements of NG consumption were studied first, based on the LMDI technique: (i) economic development, (ii) energy intensity, and (iii) energy structure. Moreover, the energy structure is further disintegrated into a non-clean and fossil energy structure to analyze the structural and substitution outcomes of NG resources. The Ordinary least square regression (OLS) and partial least square regression (PLS) methods are used for comparative analysis of the driving factors of NG consumption. Results further elaborated that fossil energy structure and per capita GDP is the most influencing factors of NG consumption, followed by non-clean energy structure, energy intensity, and population. Therefore, an optimized NG consumption strategy is required for a long-term solution to cater to increasing demand for NG consumption.

Keywords: *LMDI; Driving Factors; Natural gas consumption; OLS; PLS.*

1. Introduction

Energy is the soul of this modern age of the machine, in which human beings have significantly progressed. Life has been automated by machines nowadays, and there is a need for a reliable energy supply to continue further progress and development [1]. Nowadays, the world is concerned about two main issues, fossil fuels' depletion and the CO_2 emissions caused by the burning of fossil fuels' [2]. Globally, fossil fuels' production has peaked already [3]. It is reported from International Energy Agency (IEA) that global primary energy consumption increased with a quick pace from 2010 reaching an annual average growth rate of 2.9% in 2017 [4]. Energy and economy are directly related to each other, and the fossil fuels' volatile prices impact the global economy negatively. Global warming has forced the world to find alternatives to fossil fuels in the form of renewable energy [5]. Pakistan is ranked as the sixth most populous country in the world, with the current population of 218.6 million and an annual average growth rate of 2.04% [6]. Pakistan has 282 trillion cubic feet reserves of natural gas from which only 25-40 trillion cubic feet are recoverable. Pakistan is prone to excessive consumerism of natural gas. An estimated report states that only 19% of recoverable reserves are left [7]. In 2018, the natural gas consumption annual average growth rate stood at 7% [8]. Natural gas production growth rate during 2006-12 was 2% and -1.3% in 2018 [9];. Demand and supply gap will increase, and the remaining reserves of indigenous gas shall be exhausted in the near future [10]. Natural gas is considered essential for economic development, and it is undoubtedly a low CO2 emitting fuel as compared to its counterpart fuels [11]. Researchers used the decomposition method to analyse the emissions from natural gas consumption [12][13].
The industrialization, increase in population, urbanization and growth in rural gasification, to name a few have caused the phenomenal increase in the natural gas consumption [14]. Natural gas consumption and the factors affecting it have been under great focus over the last few decades. Many of those factors are discussed by [15]. Natural gas consumption and economic growth have causative relations as given by Granger causality [16]. GDP share by natural gas and value-added by industrial causal relationship was found for long term with the help of Vector Error Correction Model (VECM)

*Corresponding author. Tel.: N/A; fax: NA
E-mail address: ibrarbaloch77@gmail.com

[17]. There are many studies in which prediction techniques are discussed such as neural networks and fuzzy theory [18][19]. These theoretical models are used to predict the consumption of non-renewable energy. Methods discussed above only study those factors which influence natural gas consumption and cannot evaluate the internal structural effects and energy substitution effects. In this study, energy substitution effects are not ignored by using the Logarithmic Mean Division Index (LMDI) method, this technique has been used for finding the factors that internally affect the energy consumption [20][21]. Uncertainty in the estimation of the related variables of development was studied by [22]. It is discussed in many studies that ordinary least square (OLS) method having the multi-collinearity problems in the multivariate regression variables is not favourable for the scenario analysis [23] but for the black and white data having the limited observation terms and absent values or the OLS insignificant data, the ideal method of partial least squares (PLS) can be applied [24][25].
In this study, the connection between natural gas consumption and its driving factors is investigated using the LMDI method. This paper is arranged as follows: In section 2, the driving characteristics of natural gas consumption are investigated by using the LMDI method; PLS regression is utilized to evaluate the parameters. In section 3, obtained results are presented, and in the last section, the conclusion is presented.

2. Methodology

a) Investigation of Driving Factors of Natural Gas Consumption

The decomposition method, namely Log-Mean-Division-Index (LMDI) used by [26][27], possesses a strong theoretical basis with ease of implementation and adaptability. Primarily, the LMDI method suggests that energy consumption can be divided into three effects, such as collective economic development, energy intensity influence, and energy structure impact. The energy structure effect can further be disintegrated into non-clean energy structure influence and fossil energy structure influence to analyze the structural and substitution results of energy sources. Hence, this study adopts the LMDI technique to decompose the natural gas intake of Pakistan into the following driving factors:

$$NG_t = \frac{NG}{FE} \times \frac{FE}{PE} \times \frac{PE}{GDP} \times \frac{GDP}{POP} \times POP = D1 \times D2 \times I \times PG \times P \quad (1)$$

Where; NG, FE, PE, GDP and POP denote natural gas intake, fossil energy intake, primary energy utilization, gross domestic production, and population respectively. Furthermore, D1 signifies the fossil energy structure, representing the replacement of the oil and coal with natural gas. D2 indicates the non-clean energy structure, representing the overall improvements in the energy structure. I represent the energy intensity effect, representing per unit of energy required for producing economic output. PG represents per capita GDP, and finally, P represents the population. The variations in natural gas intake are recorded between (t-1) and (t) by using the LMDI method.
The decomposition of natural gas consumption in Pakistan is expressed as Equations (2)-(7).

$$\Delta NG_{tot} = NG_t - NG_{t-1} = \Delta NG_{D1} + \Delta NG_{D2} + \Delta NG_I + \Delta NG_{PG} + \Delta NG_P \quad (2)$$
$$\Delta NG_{D1} = L(NG_t, NG_{t-1}) \ln (D1_t/D1_{t-1}) \quad (3)$$
$$\Delta NG_{D2} = L(NG_t, NG_{t-1}) \ln (D2_t/D2_{t-1}) \quad (4)$$
$$\Delta NG_I = L(NG_t, NG_{t-1}) \ln (I_t/I_{t-1}) \quad (5)$$
$$\Delta NG_{PG} = L(NG_t, NG_{t-1}) \ln (PG_t/PG_{t-1}) \quad (6)$$
$$\Delta NG_P = L(NG_t, NG_{t-1}) \ln (P_t/P_{t-1}) \quad (7)$$

where $L(NG_t, NG_{t-1}) = (NG_t - NG_{t-1})/(\ln NG_t - \ln NG_{t-1})$, ΔNG_{tot} is the total natural gas consumption and is decomposed into five driving factors such as the fossil energy effect ΔNG_{D1} due to variations in fossil fuels energy structure, non-clean energy influence ΔNG_{D2} due to variations in non-clean energy structure, ΔNG_I intensity effect due to variations in natural gas intensity, the economic effect ΔNG_{PG} due to changes in per capita gross domestic production and the population effect ΔNG_P due to variations in population.

b) Investigation of Natural Gas Intensity

The impression of energy intensity on natural gas intake has been demonstrated in the previous section. The decline in energy intensity saves energy as $I = \sum_i I_i K_i$ and the energy intensity change is caused by the sectorial structure influence and sectorial energy intensity influence [28]. Therefore, for further understanding and finding the reasons for the energy intensity changes and natural gas intake growth in future, the energy intensity is decomposed using the LMDI method as follows:

$$I = \frac{NG}{GDP} = \frac{\sum_i NG_i}{\sum_i GDP_i} = \sum_i \left(\frac{NG_i}{GDP_i}\right) \times \sum_i \left(\frac{GDP_i}{GDP_i}\right) = \sum_i (e_i \times k_i) \tag{8}$$

Where i = 1, 2 indicating secondary & tertiary industrial sectors; ei is the energy intensity of i industry; and ki is the share of i industry's added GDP value. The representation of industrial structure given as below:

Where $w_i = \frac{(e_i^T \times k_i^T)-(e_i^0 \times k_i^0)}{\ln(e_i^T \times k_i^T)-\ln(e_i^0 \times k_i^0)}$, ΔI_e and ΔI_k indicate the energy intensity change caused by the industries' intensity effect and industrial structure. Above analysis incur two types of effects on the total energy intensity change: sectorial energy intensity effect and sectorial structural intensity effect.

c) Partial Least Square (PLS) Regression

The partial least square regression was proposed by researcher [29], which combines the principal component analysis and multiple linear regression analysis. Its benefits are unmatched by the OLS regression method such as the missing data problem, limited observation values and variables multi-collinearity. Number of independent variables shown as X = [x1, x2, … … , xm] and dependent variable y, each independent variable and dependent variable are n-dimensional column vectors. The dependent variable and independent variables data matrix are disintegrated into bilinear forms as represented in equations below.

$$X = t_1 p_1^T + t_2 p_2^T + \cdots + t_h p_h^T e_h \tag{10}$$

$$y = u_1 q_1 + u_2 q_2 + \cdots + u_h q_h + f_h \tag{11}$$

Where the term ui and ti (i = 1, 2, ……...,h) are the extracted latent variables from given data of the explained variable (y) and explanatory variable (X) respectively. For X variable the loading vector is pi, and the loading value is qi (i = 1, 2, ...,h). For y variable eh and fh represent the residual vectors. PLS regression method's basic working standard is discussed in the following steps: 1) the latent variables t_i and ui are separated from the number of explained variables y and independent variables X, then the terms t_i and u_i take as much data variation as possible for the better representation of X and y. 2) To confirm the connection of explanatory and explained variables to each other, when the correlation coefficient of t_i and u_i achieve the maximum degree of correlation to each other then t_i can have the robust explanatory power to u_i. Later the first main components t_i and u_i are taken out for X and y, respectively, the regression equation is built based on these components. The algorithm terminates when the required accuracy is achieved, else the residual info from the dependent and independent variables is repeatedly taken out until the precision of the results obtained reaches the necessities. In this process, the taken-out terms conclude the X variable system information, clarify the y variable and evade system violation interference. Multiple correlationproblems in regression between the variables can be resolved effectively by this method.

3. Results and discussion

3.1. Factor Decomposition for Natural Gas Consumption Changes

The sample period spans from 2006 to 2018, and the data were taken from [30] [6]. Fig 1: illustrates that the natural gas consumption changes are highly influenced by the per capita GDP changes. As per current situations, the annual average GDP growth rate has remained negative for 2019 and 2020. The energy intensity effect is the second largest influencing factor, from 2008 to 2010 energy intensity improved. When energy intensity decrease means energy efficiency improves. The third-largest influencing factor is fossil energy structure. Positive values show the substitution and increasing competition for natural gas and counterpart fuels' in the energy market. Natural gas has been used excessively due to its ease of availability and lower price; however, many coal-based plants are being installed in the country, especially after the investments in Thar coal mines. The fourth one is the non-clean energy structure, the coal and oil, which are considered dirtier energy sources. When the non-clean energy structure increases, it implies that non-clean energy share in the total energy mix has increased or the increase may have been caused by the high energy demands or reduction of the natural gas in the total energy mix. At last the population factor shows very rare affect; its changes are very small.

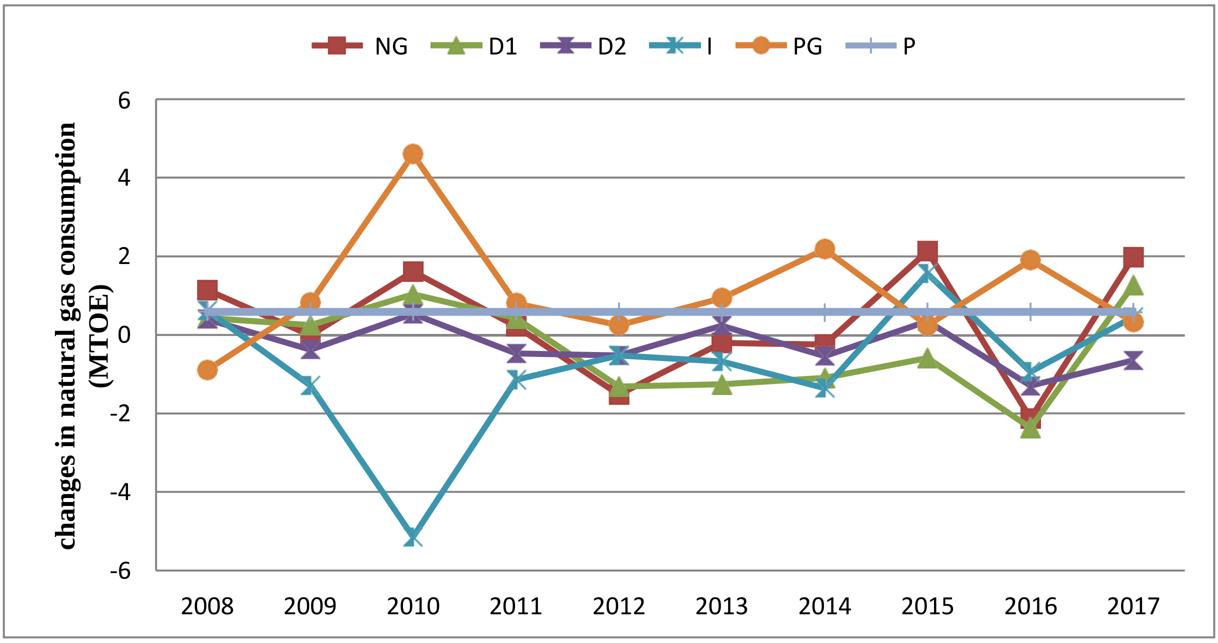

Fig. 1: Factor decomposition for natural gas consumption changes

From Fig. 1, it can be noted that there is same ratio of positive and negative values for the changes in energy structure. Same trend is expected in future due to LNG import and installation of the coal-based power plants. It is clear that when non-clean energy consumption decreases, energy efficiency improves. The population is considered to be an essential factor for the changes in natural gas intake; at the present utmost of the population in Pakistan living in rural areas have no access to natural gas. Increasing urbanization rate may put further pressure on the natural gas reserves. In Pakistan, there is no proper population policy which affects the energy consumption significantly. Population changes are positive, but the annual average growth rate is reducing due to public awareness. It can be noted that natural gas intake changed substantially from 1999 to 2012. This happened mainly due to the conversion of public vehicles on Compressed Natural Gas (CNG). Later, the Government realized that this could lead towards future gas shortage and some strict policy measures controlled the further increase in natural gas consumption.

3.2. Factor Decomposition for Energy Intensity Changes

The energy intensity changes in services (SI) has the utmost influence on natural gas intensity (NGI), followed by the industrial energy intensity (IES). The services energy intensity plays a vital role in the overall natural gas intensity. The SI and NGI changes have a similar trend and fluctuations, and due to the upsurge in SI the natural gas intensity rises. The values of industrial energy intensity changes are mostly negative and small due to efficient and non-clean technology using industries. Very few positive values reflect that with the same energy consumption, industrial output reduced means due to the minor crises in industries given less production by using the same pattern of energy. It’s clear that natural gas intensity changes with the change of services energy intensity and the industrial intensity. The services energy structure intensity and industrial energy structure intensity have small effects on the natural gas intensity. Generally, the development of industries related to technological improvement and technological improvement tends to decrease energy intensity at some level. The alteration in sectorial structure does not essentially diminish the energy intensity; the economic indicator GDP output value will decide whether the natural gas intensity incline or declines.

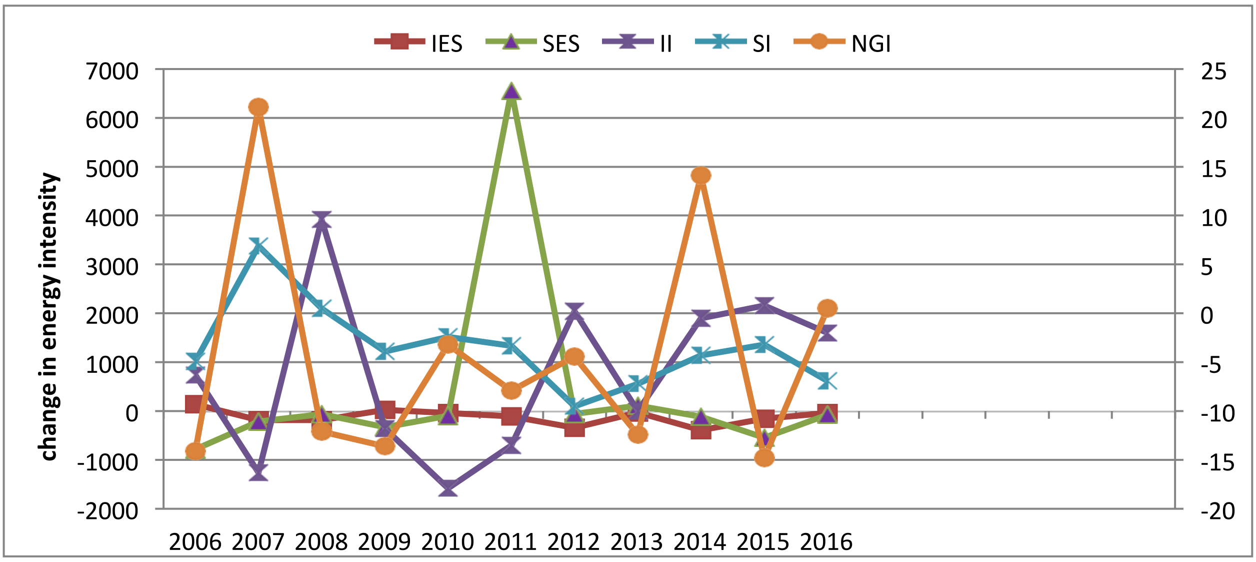

Fig. 2: Factor decomposition for energy intensity changes

3.3. OLS Estimation of Driving Factors

The ordinary least square regression relationship results of Pakistan and its driving factors are presented in Table 1. The methods results are not justifiable, and the values are larger than its degree of fit. The variable natural gas intensity (NGI) did not pass the significance test and is different than the actual condition. The variable per capita GDP square (Y) 2 is negative meaning that at low energy consumption, the output value was high. The natural gas intake will decline with the technological advancements and finding the alternatives to fulfill the energy requirements. Therefore, the estimated results of OLS are questionable.

If the value of VIF is higher than 10 in the OLS estimated results, it means that the variables are influenced by multi-collinearity. It is evident in Table 1 that VIF values for all driving factors exceed 10. If the P-value is less than 0.2 it means that data is stationary, here only the two variables data is non-stationary NGI & population. The value of R-squared must expected to be more than 90% for good result. The F-statistic ratio is less means variation among the groups is less as it was expected. The Probability (F-statistic) is the P-value of whole model, it can't be negative.

Table 1: OLS estimation of natural gas consumption based on influencing factors

Variable	coefficient	P-value	VIF
C	224.6972	0.0294	
Y	-64.247	0.0279	168656.099
Y2	4.572	0.0281	172580.739
D1	1.569	0.0159	18.664
D2	1.978	0.0526	12.862
NGI	-0.2134	0.3227	24.303
P	0.731	0.5604	149.595
Adjusted R-squared	0.7278	Multiple R-squared	0.9093
F-statistic	5.011	Prob(F-statistic)	0.107

3.4. PLS Regression

Therefore Table 2 shows the regression results of two types scaled and un-scaled, here we found the un-scaled coefficient best for natural gas estimation. It is found that per capita gross domestic production square elasticity effect on natural gas intake is 4.57196%, representing that with 1% rise in per capita GDP, the natural gas intake will increase by about 4.5719%. The coefficient of per capita GDP is negative, which means that there is an Environmental Kuznets Curve (EKC) between per capita gross domestic production and Pakistan's natural gas intake. EKC reflects that when the energy consumption increases, the per capita GDP also increases and due to the continuous rise in energy consumption, the environmental degradation increases. At some point, the environmental degradation starts declining, but the per capita GDP keeps increasing. The natural gas intake elasticity to non-clean energy structure is 1.978%. It is expected that with 1% upsurge in the non-clean energy structure, the natural gas intake increases by 1.978%. The elasticity of natural gas intake to fossil energy structure is 1.569%. This means that when fossil energy structure rises by 1%, it is projected that the natural gas intake will increase by 1.569%. Actually, natural gas is a clean and high content value energy source. It plays a vital part in environmental pollution reduction. The natural gas intensity is negative which means energy consumption is low as compare to its output value. The population elasticity effect on natural gas intake is somewhat small. The natural gas intake is expected to rise by 0.73169% with 1% increase in population. The population growth rate in Pakistan is decreasing as compared to the past due to the awareness in people.

Table 2: PLS regression results for the STIRPAT Model

Variable	Unscaled	scaled & Center
C	224.6972	224.6972
lnYt	-64.24714	-9.608987
(lnYt)^2	4.57196	9.68739
lnD1t	1.5697	0.12466
lnD2t	1.97846	0.06528
lnNGIt	-0.21343	-0.033995
lnP	0.73169	0.046637

4. Conclusion

In Pakistan, there is no proper population policy which affects the energy consumption significantly. It is found that Population changes are positive, but the annual average growth rate is reducing due to public awareness. It is found that the natural gas consumption changes are highly influenced by the per capita GDP changes. As per current situations, the annual average GDP growth rate has remained negative for 2019 and 2020. The energy intensity effect is the second largest influencing factor, from 2008 to 2010 energy intensity improved. When energy intensity decrease means energy efficiency improves. The energy intensity changes in services (SI) has the utmost influence on natural gas intensity (NGI), followed by the industrial energy intensity (IES). The ordinary least square regression relationship results of Pakistan and its driving factors are presented in Table 1. The OLS methods result are not justifiable, and the values are larger than its degree of fit. The variable natural gas intensity (NGI) did not pass the significance test and it is different than the actual condition. The variable per capita GDP square (Y) 2 is negative means that at low energy consumption, the output value was high. If the value of VIF is higher than 10 in the OLS estimated results, it means that the variables are influenced by multi-collinearity. It is evident in Table 1 that VIF values for all driving factors exceed 10. If the P-value is less than 0.2 it means that data is stationary, here only the two variables data is non- stationary NGI & population. This indicates that there is a severe multi-collinearity between the variables. The regression result shows that the per capita gross domestic production square elasticity effect on natural gas intake is 4.57196%, representing that with 1% rise in per capita GDP, the natural gas intake will increase by about 4.5719%. The coefficient per capita gross domestic production is negative, which means that there is an Environmental Kuznets Curve (EKC) between per capita gross domestic production and Pakistan’s natural gas intake. EKC reflects that when the energy consumption increases, the per capita GDP also increases and due to the continuous rise in energy consumption, the environmental degradation increases. At some point, the environmental degradation starts declining, but the per capita GDP keeps increasing.

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