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A COMPARATIVE ANALYSIS OF COAL-GAS SUBSTITUTION IN CEMENT SECTOR OUTPUT AS DERIVED DEMAND FROM PAKISTAN'S INFRASTRUCTURE DEVELOPMENT

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Abstract

Structural changes in an economy depend on the development of physical infrastructure, which is crucial for the socioeconomic growth of any country and drives the demand for cement. Cement is a vital component for all sectoral transformations, such as the building industry, residential construction, and large-scale infrastructure projects. In light of rapid physical infrastructure development, this research employs the Cobb-Douglas production function to carry out a comparative analysis of coal-gas substitution in the cement sector's output from 1990 to 2022. For both the long and short-run relationships, the study uses Error Correction Models based on the Cobb-Douglas production function. The results of the long-run and short-run models indicate a unidirectional causality effect from coal and natural gas consumption to output growth. Additionally, the statistically significant substitution effect from natural gas to coal consumption at the rotary kiln process reveals that coal conservation policies will reduce the growth performance of the cement sector, which is associated with environmental degradation, and lead to a decline in economic development. In contrast, the use of natural gas in the cement sector has the least influence on carbon dioxide emissions levels and is a more sustainable option. To achieve sustainable growth for physical infrastructure development, the Government of Pakistan should provide relative cost incentives to cement producers to shift their consumption patterns from coal to natural gas.

Keywords: coal consumption, natural gas consumption, output growth, ECM.

1. INTRODUCTION

The classical theory of structural transformation was developed by Arthur W. Lewis in 1954, who described sectoral duality within an economy of a developing country experiencing structural and geographical processes of transforming the traditional sector into a modern sector. This transformation of an economy necessitates the development of physical infrastructure, which serves as the foundation of social-economic development in any country. Socio-economic development is a multi-faceted mechanism that promotes the upward mobility of the entire social and economic system and brings the underprivileged class in backward areas to an acceptable level of living standard enjoyed by people in modern areas through balanced physical infrastructural development, as defined by Gunnar Myrdal in his pioneering work. Physical infrastructure development involves constructing and maintaining essential services, such as schools, hospitals, homes, business workplaces, roads, and transport networks, which society relies on. Additionally, physical infrastructure development, including improved road networks and rail tracks, is crucial in delivering goods and services to consumers and enhancing the geographical mobility of laborers from the traditional sector to the modern sector, as well as transporting travelers to their workplaces or for tourism purposes.

At both the national and regional levels, cost-reducing road networks not only enhance the purchasing power of consumers but also increase the circulation of human and non-human resources within geographical boundaries and decrease the transportation costs of raw materials utilized in the production of final goods (Kabashkin, 2007; Meirane, 2007; Meidutė, 2007; Vasilis Vasiliauskas, Jakubauskas, 2007; Vasilis Vasiliauskas, Barysiene 2008a, 2008b; Morkvėnas, et al. 2008; Kiisler, 2008; Baublys, 2009). In terms of its role in international trade development, the history of international trade presents an interesting dichotomy by overlooking the significance of physical infrastructure development in providing producers with cost competitive advantages in both domestic and international markets through reduced transportation costs (Smith, 1776; Ricardo, 1817; Mill, 1848; Heckscher-Ohlin's, 1979). In addition to the principles of classical trade theories, physical infrastructure development has gained considerable importance in the present era of global and regional economic connectivity (Gunnar Myrdal, 1972; Rehman et al., 2020; Xu, 2020). From a broader perspective, the decrease in production costs has a positive and productive impact on socio-economic development, including the upward adjustment of real incomes and consumption patterns of society, as well as an increase in the export shares of domestic goods in foreign markets, all of which contribute to the overall economic growth of a nation.

In developing countries, the construction of physical infrastructure is critical for boosting economic growth by bridging the gap between underdeveloped and modern areas, which relies heavily on materials like cement. Cement is a vital component in various sectors such as the building industry, residential construction, and large-scale infrastructure projects, all of which contribute to the demand for cement. Rapid infrastructure development is essential for many developing countries to achieve economic growth, as reflected by the significant increase in cement production (Shraddhaet al., 2014). The growth rate of infrastructure development is a key indicator of a country's economic development, which in turn drives the production of cement (Joseph, 1994). As cement products are widely used in construction, it is produced in almost every country, with raw materials such as coal and natural gas playing a crucial role in its production.

Based on the findings of Kheni et al. (2008), consisting of both developing and developed countries, the cement industry can be considered as the primary sector in the construction industry. This industry is responsible for transforming various resources into constructed facilities through maintenance, repair, and construction. The private and public opportunities in this sector range from residential buildings to non-residential resources such as bridges, canals, dams, road and rail networks, and heavy construction, which all play a crucial and highly tangible role in economic development. The production of cement is closely linked to the process of physical economic development, and improvements in cement production are primarily influenced by the energy factors used as a major input in rotary kilns. Coal and natural gas, which act as substitute goods in the kiln process, are the primary energy sources used in rotary kilns, and the estimated value of energy consumption, including coal and natural gas, for the cement sector is approximately 2 percent of the global energy consumption and almost 5 percent of the total global industrial energy consumption (Ernst et al., 2001).

Pakistan's economy has been included in the list of developing and emerging economies due to its lower level of physical infrastructure development for economic growth as compared to developed economies, as stated in the World Economic Outlook Report 2000 released by the International Monetary Fund (IMF). To achieve the status of a developed economy by 2060, the country has initiated various physical infrastructure development projects since the start of economic reforms in 1990 and the China-Pakistan Economic Corridor (CPEC) initiative in 2015. These efforts aim to enhance the standard of living for the lower and middle classes by improving their social and economic well-being and providing essential goods at a lower cost. Pakistan has emerged as a critical driving force in the global economy through its rapid progress in physical infrastructure development and structural transformation.

Over the past few years, the growth in economic activity and investment in infrastructure projects under the CPEC (China-Pakistan Economic Corridor) and PSDP (Public Sector Development Program) as well as private housing schemes has contributed to an increase in the cement sector's share of overall manufacturing sector output. Additionally, the trend towards healthy marginalization to boost cement demand has prompted manufacturers to expand their production capabilities from 49.4 million tons to 72.8 million tons, leading to increased use of energy raw materials such as coal and natural gas. The energy utilized by the cement sector primarily consists of factors used for heating clinker in kilns, generating clinker through pyro-processing raw materials in large rotary kilns at high temperatures, and crushing the resulting product into fine cement powder. Given the significance of the cement sector to economic development, it is crucial for policymakers to assess how energy factors used in production might respond to improvements in other sectors of the economy. This is especially important and empirical assessment in the light of the rapid physical infrastructure development.

2. LITERATURE REVIEW

A wide range of theoretical and empirical research has investigated the relationship between economic growth and energy consumption in both industrialized and non-industrialized countries. Many studies have employed a growth model that utilizes the parametric method and incorporates control variables such as labor, exports, imports, domestic investment, urbanization, and population. In contrast, some studies have analyzed the positive and negative effects of the cement sector on output growth, energy consumption, and environmental degradation using non-parametric statistical techniques. To better understand the empirical relationships among the variables and to simplify the literature review, it can be divided into macro-based and micro-based literature, based on the nature of econometric techniques and past studies.

2.1 macro-based literature review

The macro literature is rooted in the theoretical and empirical literature that was derived from past studies using the parametric method. These empirical studies investigate the association between economic growth and energy consumption, which was first explored by Kraft (1978) in his pioneering work on the US economy. Kraft's work provided empirical evidence of a causality effect, demonstrating how marginalization in economic activities influences energy consumption. Subsequent studies by Erol and Yu (1987) for West Germany, Masih and Mashi (1996) for Indonesia, Soytas and Sari (2003) for South Korea and Italy, and Narayan and Smyth (2005) for Australia have yielded similar results, contributing to the body of empirical literature.

In contrast to earlier research, Yu and Choi (1985) and Yu and Hwang (1984) did not find any causal relationship between energy consumption and economic growth in their respective investigations. Conversely, Lee (2005) posited that energy consumption influenced economic growth in developing countries, and his findings supported the energy conservation hypothesis, which demonstrated a unidirectional causality effect from energy consumption to GDP growth. According to this hypothesis, energy-dependent countries like those in the developing world are susceptible to having their GDP growth rate hindered by a shortage in energy supply. Moreover, Jamil and Ahmad's (2011) Pakistan-specific study revealed that electricity demand is highly responsive to changes in economic activity at both the aggregate level and in the major sectors of the economy.

Jinke and Li (2011) investigated the relationship between coal utilization and economic activities in India and China. They determined that economic activities have a Granger causality effect on coal utilization processes in China, while coal utilization in India has a unidirectional causality effect on output growth. Kumar and Shahbaz (2012) re-examined the causal relationship between economic activities and coal utilization in Pakistan by using a growth model from 1971 to 2009 and applying various tests, including the endogenous two-break unit root test, ARDL approach, DOLS, FMOLS, and VECM Granger causality test. Their results show that labor, capital, and coal utilization have a positive impact on economic growth in the long run, while coal utilization and output growth are causally related in the short run.

The research conducted by Zhang et al. (2012) and Liu et al. (2017) within the realm of physical infrastructure development highlighted the significance of the ecosystem concept. This concept incorporates ecological principles that are governed by energy utilization theories, which serve as the driving force behind urban systems in their respective economies. Both sets of researchers examined the structural relationship between urbanization and energy utilization in developing economies, such as China, as a case study. They posited that rapid urbanization inevitably leads to an increase in energy utilization through modern communication systems and urban transportation development. Their studies provided empirical evidence that energy utilization is rapidly increasing in developing countries like China as they industrialize, but is already high in developed countries.

On the contrary, Liu (2006) discovered that infrastructure development plays a smaller role in total energy consumption compared to economic growth. Furthermore, the theoretical literature encompasses Wasim and Siddiqi's (2018) multidimensional examination of physical infrastructure development, such as the CPEC projects, which they believe present a golden opportunity for the Pakistan cement and steel sector to address its economic and social issues by employing excess labor, offering goods and services to the Pakistani people at a lower cost, increasing labor mobility across and within borders, and fostering regional connectivity among neighboring countries.

2.2 micro-based literature review

According to micro studies conducted at a firm-specific level using a non-parametric approach, marginalization in cement sector production plays a significant role in the emission of carbon dioxide. This occurs through the decarbonization of limestone and the combustion of fossil fuels, as reported by Ernst, Lynn, Nathan, Chris, and Leticia (2001). The authors also highlighted potential carbon emission mitigation options, such as transitioning from high carbon (coal) to low carbon (natural gas) sources, enhancing energy efficiency, and increasing the use of additives in cement production. Yeonbae and Ernst (2002) conducted a decomposition analysis to examine the relationship between energy utilization and carbon dioxide emissions from the cement industry in Brazil, China, South Korea, and the United States between 1980 and 1988. Their analysis identified four key factors: energy consumption, energy efficiency, level of economic activity, and production structure. Results indicated that marginalization in the cement sector production is the primary driver of increased carbon dioxide emissions in all observed economies, except for South Korea, where structural transformation in the production process is the most significant factor. Boqiang and Zihan (2016) applied the Logarithmic Mean Divisia Index (LMDI) for decomposition analysis in the Chinese cement industry and found that energy intensity is the primary driver of reduced carbon dioxide emissions. Additionally, a decline in labor productivity is the main contributor to the increase in carbon dioxide emissions between 1991 and 2010.

Multiple case studies have been developed via non-parametric methods in the empirical research for examining different aspects of the Pakistan cement industry. Pakistan's cement sector is well-established and ranks as the 14th largest producer and top 5 exporters globally (Memon et al., 2012). A recent study utilized the Index Decomposition Analysis (IDA) along with the Logarithmic Divisia Index Model (LDIM) to analyze CO2 emissions from the Pakistan cement industry between 2005 and 2020 (Rizwan et al., 2022). According to LDIM, the main drivers of carbon emissions in the Pakistan cement sector include energy intensity (− 0.63%), energy structure (0.06%), carbon intensity (− 0.87%), labor productivity (12.03%), and growth in the cement sector (6.34%). The production of cement powder through the breakdown of gypsum and limestone in coal-fired power plants generates greenhouse gas emissions (Ali et al., 2011). Direct greenhouse gas emissions are released during the clinker process, while indirect emissions result from increased electricity consumption and the burning of fossil fuels (Attari et al., 2016; Shahzad et al., 2017).

2.3 summary of literature review

The multi-dimensional literature review, including macro level developed via a parametric approach and firm-level analysis explained via a non-parametric approach, has led us to the conclusion that no studies have been conducted at the firm level to examine the existence and nature of any causal relationship between coal and natural gas consumption and output growth in Pakistan's cement sector. Therefore, this study aims to fill this literature gap with parametric and sectoral-level approaches, statistically expressing the relationship between coal and natural gas consumption and output growth in Pakistan's cement sector in the context of rapid physical infrastructure development. A Cobb-Douglas production function is used to analyze the magnitude of substitute energy factors in the process of the rotary kiln, where cement output is positively related to the level of natural gas or coal consumption in crushing the raw materials into fine cement powder. The analysis of sector-level data would be suitable to determine the heterogeneous impact of coal and natural gas on cement output, in order to develop energy policies that promote favorable and clean growth in the cement sector.

3. HISTORY AND PRODUCTION STRUCTURE OF PAKISTAN CEMENT SECTOR

At the time of Pakistan's independence, it lacked the necessary equipment for economic development. To transform the traditional economy into an industrial and modern one, a fundamental expansion and new development of the cement sector were required. Due to the large amount of cement needed, it could not be easily imported from other countries during shortages. Pakistan has an abundance of clay, gypsum, coal, and limestone, which can sustain the growth of the cement sector for another fifty to sixty years. It was deemed necessary to develop Pakistan's infrastructure and manufacturing sector with domestic construction materials, like cement.

When the region of Pakistan and India separated, Pakistan inherited four cement plants with a total capacity of 0.5 million tons. Presently, Pakistan has 24 cement industries with an estimated total installed capacity of 46-49 million tonnes (Agha, 2014; Ali, et al. 2015). The construction of numerous cement plants has significantly improved the cement sector's productivity, and this growth has driven the cement industry in Pakistan, which not only meets domestic cement demand but also exports excess cement to foreign markets. According to the State Bank of Pakistan (2020), cement exports have increased from 103.7 million dollars in 2006 to 643.6 million dollars in 2020. The growth in cement exports can be attributed to demand from countries such as the United Arab Emirates, Afghanistan, India, Sri Lanka, Iraq, Russia, and several African nations. Since the 2000s, the cement sector's growth has attracted many foreign investors due to the abundance of raw materials like lime, gypsum, coal, and gas, which are readily available within Pakistan at a lower cost.

In Pakistan, many cement companies are situated in close proximity to mountainous regions that provide a reliable source of raw materials to reduce transportation costs and distance. These regions are rich in clay, iron, lime, gypsum, coal, natural gas, and mineral resources, offering both geographical and cost-effective incentives for cement producers to use energy factors such as coal or natural gas in the production process. After considering the importance of energy factors, the two key ingredients in cement production, lime and gypsum, are also abundant in the country. According to an exploratory survey conducted by the Pakistan geological department, the annual production of lime and gypsum is estimated at 8,698,573 metric tons and 384,513 metric tons, respectively.

In addition to these natural resources, Pakistan has more than 63 trillion cubic feet (tcf) of natural gas reserves, as reported by the petroleum division. Out of this, the cement sector has consumed 15,335.000 Cub ft mn in 2006 to 583.000 Cub ft mn in 2020. Pakistan also has 3,377 million tons (MMst) of proven coal reserves, which ranks 20th in the world. The cement industry in Pakistan consumes approximately 6,600,000 tons of coal per year. Therefore, cement is an intermediate product that requires significant investment in physical infrastructure, production-feasible locations, and sufficient resources in specific areas. These factors not only play a crucial role in the performance of the cement sector but also attract domestic and foreign producers to invest in the cement industry.

As stated by Ali et al. (2015), the Pakistan cement sector's production process can be divided into three stages, as shown in Figure 1: raw material processing, clinker production, and finish grinding processing (final cement product). The first stage involves processing raw materials to reduce their size from 120 cm to 1.2–8 cm, creating a homogeneous mixture with the appropriate chemical composition (Madlool et al., 2015), which is extracted from quarries. In the second stage, the kiln performs a heating process using energy factors such as coal or natural gas consumption to heat the raw materials to 1000-1400 0C for clinker formation of calcium silicate crystals-cement particles. Over 70% of coal and less than 30% of natural gas are consumed in the production of clinker materials, which enter the final cement powder after the processes of final milling and cement storage in silos in the third stage (Ali et al., 2011).

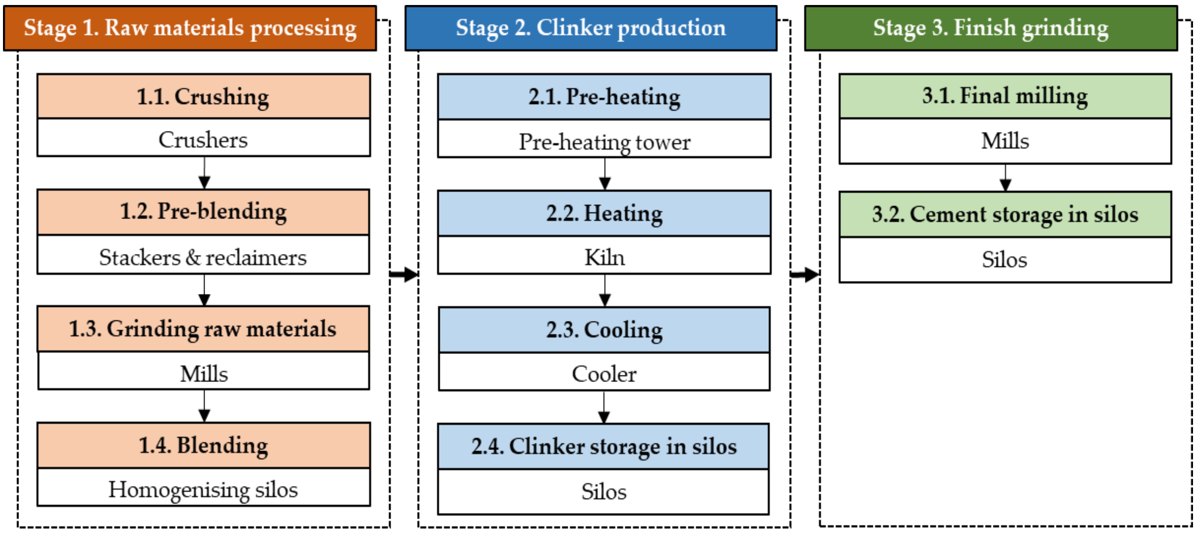

Figure 1. Production Structure of Cement Sector

4. STATISTICAL ANALYSIS OF CEMENT SECTOR'S PERFORMANCE

In Pakistan, both private and public schemes encompass a variety of construction activities, ranging from residential buildings to non-residential resources, which play a crucial and catch-up role in creating cement demand from the household, private investors, and government sectors. The development of the cement sector in Pakistan, dating back to the 2000s, is closely linked to the expansion of physical infrastructure development projects, including the CPEC and PSDP initiatives. The CPEC project, launched in Pakistan in 2013, is an economic corridor that falls under the One Belt and One Road Initiatives (OBOR), encompassing seaports and airports, railway lines, motorways, bridges, energy projects for electricity generation, special economic zones, and other related facilities. The primary goal of this mega project is to improve the standard of living for people in both China and Pakistan by exploring bilateral investment and economic trade opportunities, promoting connectivity and logistics, and fostering people-to-people contact for regional connectivity. The regional connectivity is a vital aspect of China's One Belt One Road (OBOR) initiative, which connects blue and road networks among more than 60 countries, including East Asia, Europe, Pakistan, Afghanistan, Iran, and Central Asian states. The initiation of regional connectivity has increased the demand for essential construction materials, such as cement and steel, and Pakistan's Cement and Steel sector has benefited geographically and circumstantially from the CPEC projects (Mariam, 2015; Ayaz, et al. 2016; Iram, Usman, Hafiz, and Shahzad, 2017; Rizvi, 2017; Saif and Zhao, 2017; Wasim and Siddiqi, 2018).

Secondly, the PSDP (Public Sector Development Program) is an annual policy mechanism designed to achieve the government's social and economic objectives through sustainable and inclusive development. This includes the rehabilitation and expansion of major power sector and mega water projects, such as Mangla, Tarbela, Warsak power stations, and Dasu, Diamer Bhasha, and Bunji multipurpose projects. Additionally, the government has initiated large highway and motorway projects outside the scope of CPEC, which have created backward spillovers for the construction industry due to derived and construction-elastic demand.

The initiation of CPEC and PSDP projects has had ripple effects on the construction industry, particularly in the cement and steel sectors, which can contribute to the overall well-being of the nation since the implementation of economic reforms in 1990. In terms of the distribution of economic benefits between the two sectors, the cement sector has garnered greater technical benefits from physical infrastructure development programs than the steel sector due to the extensive use of cement in construction projects. Consequently, the cement sector has grown to become the fourth-largest industry in terms of output contribution, surpassing the textile sector, which is the largest industry in terms of energy-intensive activities such as coal and natural gas consumption. Statistical analysis employs tabled and graphical methods to examine the trends of energy-driven economic activities in the cement sector in response to developments in other sectors of the economy.

The cement sector's increasing output trend is depicted in Table 1. It is worth noting that the share of cement production in large-scale manufacturing sectors' output increased from 6% in 1990-1995 to 13% in 2018-2022. A similar trend was observed in the percentage share of gas consumption in the cement sector. The total gas consumption in the cement sector increased from 10% in 1990-1995 to 11% in 1996-2000, then fell to 1% in 2018-2022. This decrease can be attributed to energy sector reforms, as the government of Pakistan introduced compressed natural gas (CNG) as an alternative fuel for both public and private sectors in 2000. As a result, the government offered numerous fiscal incentives to domestic investors to invest in the CNG sector, which created a shortage of natural gas in the economy. Consequently, coal consumption may be used as a substitute for natural gas in the cement sector. From 2000 to 2022, the share of coal consumption in the cement sector increased in total coal consumption due to the replacement of natural gas with coal, which increased the utilization of both domestic and imported coal. The primary factor contributing to the increase in the cement sector's production capacity in Pakistan during 2000-2022 is the sharp rise in cement demand in both domestic and foreign markets.

Table 1: Share of Cement Sector in GDP, and in Total Gas and Coal Consumption

Years	Share of Cement Output/Large-Scale Manufacturing Sectors' Output	Gas Consumption in Cement Sector/Total Gas Consumption	Coal Consumption in Cement Sector/Total Coal Consumption
1990-1995	0.06	0.10	-
1996-2000	0.06	0.11	-
2001-2005	0.07	0.08	0.53
2006-2010	0.10	0.05	0.59
2011-2017	0.11	0.02	0.65
2018-2022	0.13	0.01	0.75

Source: Author's Calculation

The figure 2 illustrates the cement production, domestic sales, and foreign sales of the cement sector. Domestic sales of cement in the domestic market are driven by government, private investment, and household spending for repairing and building physical infrastructure. The positive correlation between domestic sales and physical infrastructure development indicates that increasing cement demand for construction contributes to the development of the economy. From 2006 to 2014, there was a parallel trend between foreign sales and output, but after 2014, the trend diverged due to the CPEC projects between Pakistan and China, the initiation of major dam construction, and the Private Housing Scheme launched by the PTI government. These projects and programs have shifted the focus of cement producers from foreign to domestic markets, as fulfilling foreign demands may require more time and resources than domestic demands. As a result, the selling pattern has shifted from the foreign market to the domestic market in figure 2.

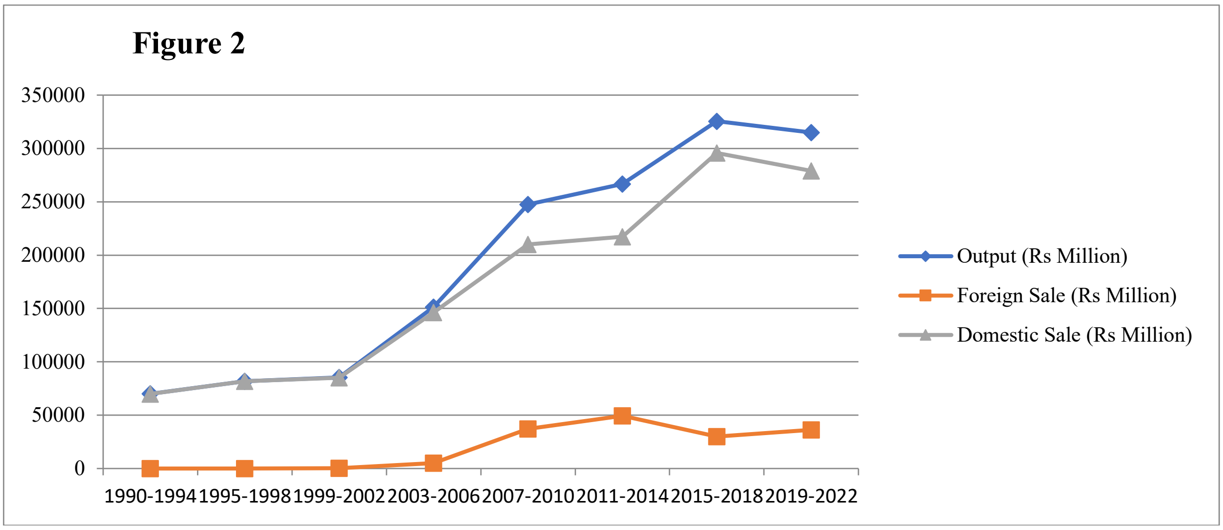

Figure 2.

In Figure 3, a negative trend is observed between coal and gas utilized in the cement sector, indicating that coal consumption for the rotary kiln process was at zero level from 1990 to 2000, as compared to gas utilized in the rotary kiln process. This is because sufficient gas supply was available to the cement sector at a cheaper rate before the energy reforms in 2000, which introduced natural gas as an alternative fuel for transport sector to replace petrol and diesel engines with the installation of CNG engines in vehicles. However, since the energy reform in 2000, the massive installation of CNG engines has converted the sufficient gas supply into a shortage supply for the cement sector, resulting in an increase in the market price of gas above the cost of coal. As a result, the increasing trend of coal utilized in the cement sector is a consequence of the replacement of gas with coal to fulfill the cement demand and produce output at a cheaper cost.

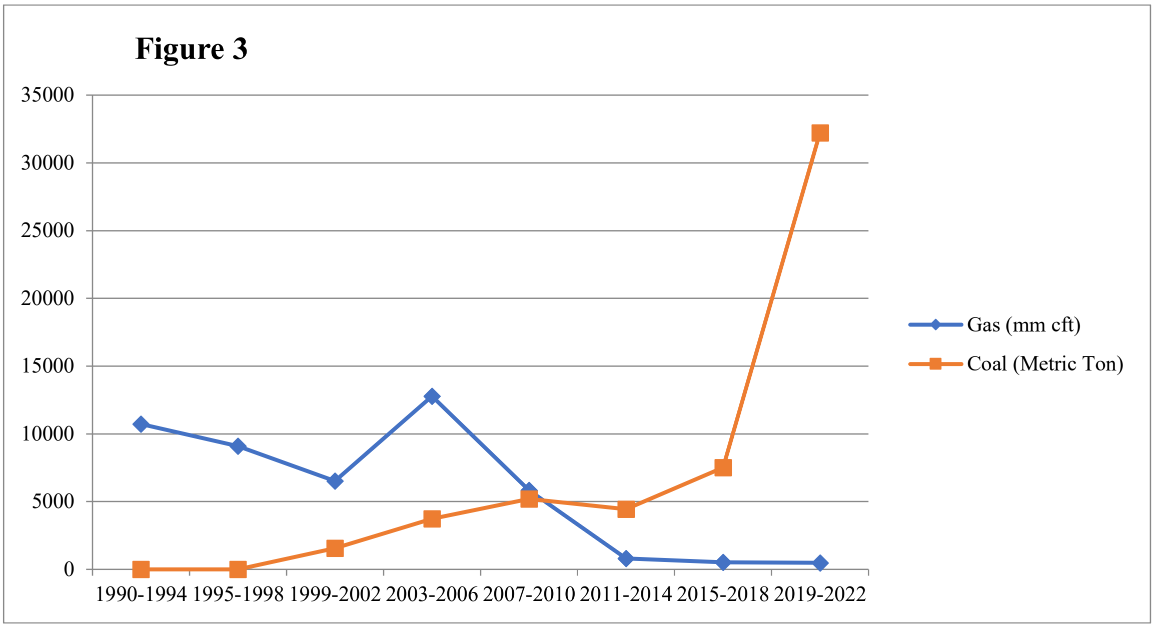

Figure 3.

5. METHODOLOGY

5.1 Theoretical model

The literature on economic development posits that the construction of physical infrastructure plays a crucial role in the production of cement, which requires primary energy factors (Kheni et al., 2008). According to Gunnar Myrdal (1972), development is a linear process that moves from a traditional society to a modern one. Physical infrastructure development can help society accommodate human habitation and reduce regional disparities in the economy by promoting balanced distribution of infrastructure. Rapid infrastructure development, rising income levels, and higher living standards can be combined with the increasing trend of energy-intensive economic activities in the cement industry.

The conversation about the relationship between economic activity and energy consumption is complex and multifaceted. Some researchers view energy as a critical component of the production process, while others believe that it plays a relatively minor role because it contributes a low percentage to the overall cost of production. Studies by Vlahinic and Zikovic (2010) and Ayres et al. (2013) have found that energy consumption is essential, just like capital or labor, in economic activity. Capital and labor cannot produce finished or unfinished goods without energy. The methodological and technical debates in the following studies by Provoski (2003) and Stern and Cleveland (2004) indicate that energy plays a fundamental role in economic activity.

The effort of labor can be substituted by additional capital with the help of energy sources. Our theoretical framework relies on the ideas of Provoski (2003) and Stern and Cleveland (2004) to assess the impact of energy factors on economic activity. Here, we are focusing on the energy factor for the cement industry in Pakistan's economy and dividing it into natural gas and coal consumption. In the development of physical infrastructure, more than 55% of the cement sector's energy demand is met through coal, while the rest is fulfilled by natural gas. To incorporate disaggregated energy factors in the cement sector model, we can modify the Cob-Douglas production function as follows:

$$Y_t = A_t C_t^{\beta 1} NG_t^{\beta 2} \tag{1}$$

Where β_1 and β_2 are non-zero, Y represents real output, A is technological progress, C is coal consumption, and NG is natural gas consumption. The log-linear form of equation (1) and the addition of a random element to equation (1) lead to the econometric specifications.

$$Ln(Y)_t = \beta_0 + \beta_1 Ln(C)_t + \beta_2 Ln(NG)_t + \varepsilon_t \tag{2}$$

The vector ε_t contains stochastic error terms with standard properties. The elasticity of coal and natural gas consumption, denoted by β_1 and β_2 respectively, is positively related to economic activity because the production process of clinker, which is a key component of cement, is generally quite energy-intensive. Clinker is made by consuming coal or natural gas, which provides the necessary heat for the combination of main limestone (CaCo3), aluminum oxides, iron oxides, and silicon oxides (Sio). The process of chemical reaction occurs in which the limestone is transformed into final cement powder.

5.2 data and variables information

The data and observations for the cement industry in Pakistan from 1990 to 2022 were obtained from the Economic Survey of Pakistan (2022). To convert the nominal series into the real series and account for inflation, the total quantity of cement produced in tons was multiplied by the price of cement and divided by the GDP deflator (Y). The disaggregate energy factors for the cement industry, coal utilization in thousand metric tons (C) and natural gas utilization in million cubic feet (mm cft), were also used.

5.3 estimation procedure

Pakistan is a rapidly developing economy with a high demand for cement due to various government projects such as housing schemes, highways, water dams, and economic zones under the CPEC project. These schemes offer significant opportunities for the cement industry in Pakistan to increase its production to meet future demand in the country. As a result of this economic growth, coal consumption for the cement industry has increased from 24.7% in 2006 to 60% in 2022, while natural gas consumption has decreased. This trend indicates the replacement of natural gas with coal in the cement production process (Economic Survey of Pakistan, 2022).

In the econometric equation (2) based on the concept of the Cobb-Douglas production function, the output of the cement sector is used as the dependent variable and is affected by the coal and natural gas consumed in the sector. Thus, it is crucial to examine the relationship between these variables. To begin, the Augmented Dickey-Fuller (ADF) test and Philip-Perron (PP) test are applied to determine the order of integration of output, coal, and natural gas consumption, which is necessary for selecting the appropriate econometric technique for the time series analysis of the relationships among variables. Since these variables are not stationary, they may have co-integrating or long-run relationships. Consequently, equation (2) is represented as an Error Correction Models (ECM).

The equation (2) can be written in the form of an Error Correction Models as follows:

$$\Delta \mathrm{Ln}(Y)_t = \beta_0 + \beta_1 \sum_{k=1}^{n} \Delta \mathrm{Ln}(Y)_{t-k} + \beta_2 \sum_{k=o}^{n} \Delta \mathrm{Ln}(C)_{t-k} + \beta_3 \sum_{k=o}^{n} \Delta \mathrm{Ln}(NG)_{t-k} + \theta_1 \hat{e}_{t-1} + \varepsilon_t \quad (2a)$$

$$\Delta \mathrm{Ln}(C)_t = \beta_0 + \beta_1 \sum_{k=1}^{n} \Delta \mathrm{Ln}(C)_{t-k} + \beta_2 \sum_{k=o}^{n} \Delta \mathrm{Ln}(Y)_{t-k} + \beta_3 \sum_{k=o}^{n} \Delta \mathrm{Ln}(NG)_{t-k} + \theta_2 \hat{e}_{t-1} + \varepsilon_t \quad (2b)$$

$$\Delta \mathrm{Ln}(NG)_t = \beta_0 + \beta_1 \sum_{k=1}^{n} \Delta \mathrm{Ln}(NG)_{t-k} + \beta_2 \sum_{k=o}^{n} \Delta \mathrm{Ln}(Y)_{t-k} + \beta_3 \sum_{k=o}^{n} \Delta \mathrm{Ln}(C)_{t-k} + \theta_3 \hat{e}_{t-1} + \varepsilon_t \quad (2c)$$

The growth rate of output is the outcome variable in equation (2a). In equations (2b) and (2c), $\Delta Ln(C)_t$ and $\Delta Ln(NG)_t$ respectively represent the growth of coal and natural gas consumption at time period t as the outcome variables. The estimates are based on the fully modified Ordinary Least Squares (FMOLS) method, which has a one-period lag of the error term in the long-run co-integration. The parameter θ_i measures the speed of adjustment, and the lagged error terms ε_i will exhibit convergence from short-term fluctuations to equilibrium in the long term. The optimum lag length ki is determined on the basis of Akaike's information criteria (AIC). The error correction model (ECM) provides results for short-run and long-run causality, which depend on the negative sign and significance of the lagged error terms.

6. RESULTS

Table 2 shows the results of the Augmented Dickey Fuller (ADF) test and Philip-Perron (PP) test for the unit root problem in the time-series data, which indicate that all variables are non-stationary at level i.e. they are integrated of order one I(1). Since all variables are stationary at first difference, this allows for the estimation of the ECM. The results of the ECM are presented in Tables 3 and 4.

Table 2: Results of the Unit Root Test

Variable	**ADF Test**		**PP Test**	
	Level	1st Difference	Level	1st Difference
LnC	-1.38	-2.12**	-1.78	-3.55*
LnNG	-1.35	-2.68*	-1.31	-4.37*
LNY	-1.45	-2.65**	-1.70	-2.79*

Note: *, **, and *** indicate null hypothesis rejection at 1, 5 and 10 % significance levels, respectively

The residual series $\hat{e}_{t-1}$ is generated from the long-run co-integrated relationship, as demonstrated by equation (2), which is estimated by using the Fully Modified Ordinary Least Squares approach (FMOLS). The findings of equilibrium in the long run are presented in Table 3, showing that the coefficient of coal consumption (0.1834) and natural gas consumption (-0.1026) is positive and significant, and negative and significant at 5 and 10% significance level respectively. This suggests that an increase of 1% in coal consumption during the production process leads to an increase in cement production by 0.18. On the other hand, as shown in Table 1 in Section 4, the substitution-based reason for the negative and situational relationship between natural gas consumption and output is due to the persistent substitution of natural gas with coal by cement producers since the energy reform in 2000, which has raised the market price of natural gas above the market price of coal. The higher market price of natural gas has given a cost-relative incentive to cement producers to shift consumption patterns from natural gas to coal used in the rotary kiln process. Thus, such substitution can create a negative relationship between output and lower gas consumption in the cement sector.

Table 3: Estimated Long-run Coefficients

Dependent Variable: Output		
Variable	Coefficient	Probability
LnC(-1)	0.1834	0.025
LnNG(-1)	-0.1026	0.103

The next step in analyzing the relationship between natural gas, coal, and output is to examine the direction of causality between them in both the long and short runs. To do this, the ECM method is employed, where the $\hat{e}_{t-1}$ variable (one period lag) is taken from the co-integrated model in the long run (Equation 2), and is estimated by using FMOLS. The t-test is used as an analysis of Granger-causality in the long run, examining the relationship between the explanatory variables and the outcome variable (θ_i, Equations 2a, 2b, 2c). The results, presented in Table 4, show that the coefficient of $\hat{e}_{t-1}$ (θ_1) is negative and statistically significant while the coefficients of $\hat{e}_{t-1}$ (θ_2,θ_3) are statistically insignificant, indicating that the significance of θ_1 reveals the long-run Granger causality running from coal and natural gas consumption to output growth of the cement sector in the context of rapid infrastructure development. Additionally, coal consumption has had a negative and statistically significant impact on natural gas consumption in the cement sector in the short run, possibly due to a shortage of natural gas supply, which has increased demand for coal. However, the influence of gas on coal consumption is not statistically significant in the short run, as the relatively higher cost of natural gas does not provide a strong enough incentive for cement producers to switch from coal to natural gas.

Table 4: Estimated Short-run Coefficients

Equation 2a, 2b, 2c				
Variable	DLnC(-1)	DLnNG(-1)	DLnY(-1)	$\hat{e}_{t-1}$
DLnY	0.15^{*} [2.23] (0.01)	-0.12^{***} [1.46] (0.07)	0.64^{***} [1.32] (0.10)	-0.34^{**} [-2.21] (0.02)
DLnC	0.46 [0.84] (0.46)	-0.26 [-0.17](0.87)	0.35 [0.39] (0.64)	-0.10 [-0.43] (0.59)
DLnNG	-0.43^{***} [-0.62] (0.08)	0.88 [0.95] (0.32)	0.11 [0.35] (0.99)	-0.41 [0.94] (0.34)

Notes: Automatic selection of lags based on minimum AIC: 0–1.
t- statistics in parenthesis [..] and probability or p-value in small brackets (...).
*, **, and *** denote rejection of the null hypothesis at 1, 5, and 10 percentlevels of significance, respectively

7. CONCLUSION

The role of construction and the cement industry's forward linkages in promoting economic development and inclusive growth are beneficial for developing countries like Pakistan, which has a significant output that ranks as the fourth-largest industry in large-scale manufacturing sectors. The expansion in production capacity over time, driven by backward spillovers from infrastructure development projects, has made the cement industry the first-largest industry in Pakistan's manufacturing sector in terms of energy-intensive economic activities. In Pakistan, cement products are driven by construction-elastic demand resulting from marginalized economic activities, particularly in the infrastructure and housing sectors. To achieve developed economy status, Pakistan has initiated various physical infrastructure development projects such as the China-Pakistan Economic Corridor (CPEC) and Public Sector Development Program (PSDP) related projects. These initiatives have increased energy utilization in converting raw materials into cement powder, as cement demand has risen for seaports, airports, the development of Gwadar city, modernization of railways, construction of an integrated road infrastructure, and the establishment of special economic zones for industrial development across the country. The main objective of this study is to assess the relationship between substitute energy factors and cement sector outputs in the context of rapid physical infrastructure development, using a quantitative assessment of how energy factors used in cement production respond to improvements in other aspects of the economy.

To obtain empirical evidence from the dataset between 1990 and 2022, Error Correction models based on the Cobb-Douglas production function are employed to examine the long-run and short-run relationships. The findings reveal that there is unidirectional causality between coal and natural gas consumption and output growth in both the short run and long run. Additionally, in the cement sector, coal consumption negatively impacts natural gas consumption in the short run, likely due to a lack of gas supply, which drives up demand for coal in the cement industry. The substitution effect from natural gas to coal consumption at the rotary kiln process has significant policy implications. Specifically, it suggests that policies aimed at conserving coal will result in a decline in output growth for the cement sector, which can lead to environmental degradation and ultimately hurt economic growth. Therefore, any policy focused on energy conservation or environmental protection in the cement sector should consider reducing coal intensity to prevent negative impacts on output and economic growth.

Alternatively, the cement sector's use of natural gas is the least influential factor in reducing carbon dioxide emission levels, compared to coal consumption proposed by Ernst, et al. (2001). Therefore, the government should prioritize the exploration of natural gas resources. Furthermore, the recent review of the Iran-Gas pipeline is promising, ensuring sufficient natural gas availability for the cement sector. In other words, rapid infrastructure development will continue to drive economic growth, even with reduced or minimal increases in carbon emissions. To achieve this, the government can provide cost incentives for cement producers to replace coal with natural gas in rotary kilns, as natural gas and coal act as substitute goods in the kiln process.

Conflict of Interest Statement:

It is declared that there are no conflicts of interest with respect to this research, its authorship, and/or publication of the article.

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