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Determinants of Electricity Demand: An Empirical Analysis of Pakistan

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Abstract

This study applies cointegration and vector error correction analysis to examine the long- and short-run relationships between electricity demand and its determinants in Pakistan from 1970 to 2008. The Johansen cointegration test confirms a significant long-run integration among variables, highlighting their enduring interconnections over time. The error correction term indicates the adjustment mechanism that restores equilibrium after deviations, reflecting the dynamic nature of electricity demand. In the short run, electricity remains a necessity, meeting essential daily needs. However, in the long run, it evolves into a luxury, symbolizing a higher standard of living and discretionary consumption. This transition underscores the shifting role of electricity from a fundamental requirement to an indicator of affluence over time. Effective management of electricity demand requires strategic policy interventions. The study emphasizes the need for price and income policies, along with targeted pricing mechanisms such as group pricing and peak-load pricing. These approaches can optimize electricity consumption while maintaining economic stability. Policymakers should focus on structuring electricity tariffs to reflect demand variations, ensuring affordability for lower-income groups while promoting efficiency. Additionally, demand-side management strategies should be implemented to address consumption patterns and mitigate excessive electricity use. Understanding the intricate relationship between electricity demand and economic factors can guide sustainable energy policies. Future research should explore additional determinants, including technological advancements, urbanization, and industrial expansion, to develop comprehensive strategies for managing electricity demand effectively in Pakistan's evolving economic landscape.

Keywords: electricity demand, cointegration, vector error correction analysis

JEL Codes: C30, L94

1. INTRODUCTION

Electricity is widely acknowledged as the cornerstone of an economy's prosperity and progress, playing an indispensable role in fostering socio-economic development. Its pivotal importance stems from its pervasive influence on various sectors, serving as a catalyst for growth, innovation, and improved living standards. This broad consensus is also emphasized in empirical studies such as Iqbal (2018), Ahmad (2018), and Wiafe (2018), who note that electricity remains a primary driver of national development. In essence, electricity stands as a fundamental driver that underpins the socio-economic fabric, enabling nations to achieve sustainable development and enhance the quality of life for their citizens, a relationship similar to the findings of Okurut and Mbulawa (2018) in Botswana and Gorus and Groeneveld (2018) in Vietnam. Over time, the swift pace of development and technological innovation has led to a substantial escalation in the utilization of energy resources. Consequently, there has been an instantaneous surge in the demand for energy, coinciding with a concurrent reduction in available resources. This juxtaposition highlights a pressing challenge wherein the growing need for energy is outpacing the available resources, emphasizing the critical importance of sustainable and efficient energy management practices. This perspective aligns with global evidence provided by Zhang (2018) for Japan and Muhieddine (2018) for Lebanon. Hence, addressing the escalating energy demand necessitates insightful and practical research efforts. This particular body of literature delves into the realm of "electricity demand," recognizing its significance as a crucial energy source on a global scale and particularly within the context of Pakistan, as also reflected in Hussain (2018) and Manzoor and Agha (2018). In the Pakistani landscape, electricity stands out as one of the most extensively utilized energy resources, making the exploration of its dynamics and management imperative for informed decision-making and sustainable energy practices, an issue similarly highlighted by Ali and Audi (2016) and Ali and Rehman (2015).

Electricity serves diverse purposes across residential, industrial, commercial, and agricultural sectors, establishing itself as an indispensable necessity within each domain. Its ubiquitous application underscores its integral role in powering essential functions and processes, contributing significantly to the overall functionality and productivity of these sectors. This broad sectoral influence is consistent with findings from Singh and Kumar (2018) in India and Clark and Adam (2018) in the United States. Presently, Pakistan is grappling with the most severe energy and electricity crisis in its history. The deficit in electricity supply has surged by approximately 5000 megawatts, leading to a substantial escalation in daily load shedding from 8 to 14 hours. This persistent power shortage has had cascading effects, precipitating a decline in industrial growth and adversely impacting the overall economy. Similar trends have been documented by Ali et al. (2016) in their analysis of financial development and energy pressures. The repercussions of this crisis are multifaceted, posing significant challenges to the nation's economic stability and development. Among the various contributing factors to the electricity crisis, the escalating demand for electricity emerges as a pivotal element, a phenomenon also explored in Ahmad (2018) and Ali and Zulfiqar (2018). Consequently, this research study meticulously examines the estimates and determinants of electricity demand, aiming to provide comprehensive insights for more effective policy management. By scrutinizing these aspects, the study seeks to contribute valuable information and recommendations that can guide strategic interventions to address the challenges posed by the increasing demand for electricity. Insights from Siddiqi (2018) on Pakistan's mutual funds and from Ali (2018) on financial markets also highlight the broader implications of structural constraints on resource allocation. This study investigates the influence of real income, electricity prices, the stock of electric appliances, and the number of customers on electricity consumption. Through a rigorous examination of these variables, the research aims to elucidate the intricate relationships and dynamics that shape patterns in electricity consumption. This framework aligns with the analytical approaches of Asif and Simsek (2018) and Wali (2018), who emphasize the role of structural and behavioral determinants in economic decision-making. The findings from this analysis are poised to contribute valuable insights into the multifaceted factors influencing electricity usage, thereby informing potential strategies for efficient energy management and policy development. This study delves into the contemporary electricity crises, meticulously examining their root causes, influences, and consequential impacts, consistent with the macroeconomic observations of Ali (2015) and Ali and Bibi (2017). Furthermore, it conducts empirical analyses of electricity demand spanning the extensive period from 1970 to 2008. Through this comprehensive examination, the research seeks to provide a nuanced understanding of the ongoing electricity challenges, offering valuable insights that can inform strategic responses and policy measures to address the complexities surrounding electricity demand. Relatedly, comparative

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energy studies such as Maurya (2018) and Luna and Luna (2018) also emphasize the necessity of long-term empirical assessments in understanding energy-market dynamics.
The primary objective of this research study is to formulate an accurate estimation of the electricity demand function in Pakistan, operating at both aggregate and disaggregate levels. Through a meticulous analysis, the study aims to unravel the underlying factors and dynamics shaping the demand for electricity, providing valuable insights that can inform policy decisions and strategic interventions in the energy sector. The importance of accurate demand modelling is similarly emphasized in Shahbaz (2018) regarding financial determinants of firm decisions and Riaz and Safdar (2018) in the context of institutional service delivery. This research study endeavors to assess the influence of electricity demand determinants in both the short and long run. It systematically analyzes the factors shaping electricity demand to discern their respective impacts over varying time horizons, an approach echoed in Ali and Ahmed (2014) and Marc and Ali (2016). Additionally, the study delves into the discourse surrounding the ongoing energy crisis, providing an in-depth examination of its current manifestations, root causes, and potential consequences, similar to insights from Ali et al. (2015) on macroeconomic strain and Ali and Audi (2018) on policy-induced fiscal dynamics. The dual focus on understanding demand determinants and addressing the contemporary energy crisis contributes to a comprehensive exploration of critical issues within the energy landscape. The discourse in this study furnishes valuable policy implications aimed at fostering a more robust management of electricity demand for governmental consideration. The identified outcomes are designed to offer practical guidance, facilitating informed decision-making to address the complexities associated with electricity demand and contribute to the development of a healthier and more sustainable energy framework. This policy dimension corresponds with the governance-oriented analyses of Khan and Ahmad (2018), Khan and Ali (2018), and Ali and Naeem (2017), who highlight the indispensable role of institutional reforms in addressing resource imbalances.

2. LITERATURE REVIEW

The practical implications and analytical examination of electricity demand have become increasingly pressing concerns over the last few decades, characterized by challenges in estimation, validity, and substantial fluctuations. Recognized as a linchpin for economic prosperity and progress, electricity assumes a pivotal role in socio-economic development. It is not an exaggeration to assert that electricity functions as the engine of growth, wielding significant influence both domestically and globally. This underscores the critical need for comprehensive understanding and effective management of electricity demand to sustain and propel economic advancement. The escalating demand for electricity underscores the heightened significance of research within the electricity sector. Simultaneously, the scarcity of electricity resources necessitates a meticulous examination of demand policies. According to projections by the International Energy Agency, developing countries are anticipated to augment their portion of global electricity consumption from 20.5 percent in 1999 to 35.8 percent in 2020 (IEA, 2002). Consequently, addressing the intricacies surrounding electricity demand becomes imperative, emphasizing the need for comprehensive policies to effectively manage this critical resource. Prior investigations into electricity demand have underscored the pivotal role of electricity in driving economic progress and development. Ghosh (2002) highlights the centrality of electricity as a crucial infrastructural input for socio-economic development. The effectiveness and significance of electricity are notably apparent in contemporary society, as also emphasized by Ghader et al. (2006). These insights collectively reinforce the indispensable nature of electricity in fostering individual well-being and broader societal advancement. Filippini and Pachauri (2004) elucidate that the upward trajectory in industrialization, population expansion, income growth, modernization, and urbanization has been instrumental in augmenting electricity consumption in the past. Furthermore, they posit that this trend is anticipated to intensify in the future, necessitating substantial investments to effectively address the burgeoning demand within the electricity sector. The elucidation underscores the imperative for strategic planning and investment to meet the evolving needs of a growing and modernizing society. Filippini and Pachauri (2004) further advocate for the significance of demand-side management in the context of constrained electricity supply. They posit that economic progress, promotion, and sustainability necessitate significant utilization of energy and electricity resources to stabilize the escalating demand and development. This underscores the critical role of electricity, which exhibits a high level of elasticity in response to economic growth and development. The recognition of demand-side management becomes pivotal in optimizing resource utilization and ensuring the stability of the electricity sector amid growing economic activities.
Electricity assumes a crucial role in driving economic development and growth. To discern the correlation between electricity consumption and economic growth, scholars often employ the Electricity Intensity ratio, calculated as the ratio of electricity consumption to GDP. This metric provides a quantitative measure of the relationship between the utilization of electricity and the overall economic output, serving as a valuable indicator in assessing the impact and efficiency of electricity in fostering economic development. The Electricity Intensity ratio (electricity consumption/GDP) serves as a metric that illuminates the extent and variation in electricity usage across different countries. Al-Faris (2002) elucidates the significance of this ratio as a crucial indicator. A higher value of the electricity intensity ratio indicates a propensity for electricity consumption to outpace GDP growth, signaling an anticipation of accelerated growth in electricity consumption relative to the overall economic output. This insight becomes valuable in predicting and understanding the dynamics of electricity consumption in relation to economic growth. De Vita et al. (2006) delve into the concept of electricity intensity, emphasizing its implication of causality between electricity consumption and economic growth (GDP). This observation holds critical significance for policy considerations, as it underscores the bidirectional association between electricity consumption and economic growth. The intricate relationship suggests that policies aimed at controlling electricity consumption may potentially impact economic growth, and vice versa. The findings accentuate the need for a nuanced and balanced approach to policy formulation, recognizing the interdependence between these two vital elements in economic development. Theoretically, numerous studies have conceptualized the electricity demand function as a derived demand, contingent upon the household and firm's production theory. Filippini and Pachauri (2004) expound upon the production theory, which posits that economic agents employ input factors to generate output. In this context, the demand for electricity is perceived as a derivative of the underlying production processes, where the consumption of electricity is an instrumental input in the larger framework of economic activities and output generation. This theoretical foundation enriches the understanding of the intricate relationship between electricity demand and the broader economic production landscape.
According to Narayan et al. (2007), the production of a unit of product necessitates input factors, with electricity being a crucial element. Consequently, electricity demand becomes an integral component of the overall production function. Similarly, Vete (2005) has formulated a theoretical electricity demand model based on household production theory, emphasizing the role of

electricity in the household production process. Building upon this theoretical foundation, various economists have developed diverse models, each tailored to capture the nuanced relationships and factors influencing electricity demand. These models serve as valuable tools for understanding and predicting the intricate dynamics of electricity consumption within different economic contexts. Erkan (2007) delineates two models for electricity demand function: the "reduced form model" and the "structural form model." The reduced form model encapsulates a direct linear association between electricity demand and its determinants. In the context of this specific research study, the chosen approach is the reduced form model. This modeling choice signifies a focus on establishing a straightforward and direct relationship between electricity demand and its influencing factors, providing a practical framework for analysis and interpretation within the scope of the study. The reduced form model, often referred to as the double-log linear demand model, establishes a direct and linear relationship between electricity demand and its determinants. In contrast, the "structural form model" takes a disaggregate approach, representing the electricity demand model as a set of equations. This structural form is also known as an indirect demand function, capturing the interdependencies and interactions between various factors influencing electricity demand through a system of equations. The choice between these models depends on the research objectives and the level of detail required to comprehensively understand the dynamics of electricity demand.

In the estimation process, Erkan (2007) has employed a dynamic form of the reduced model known as the partial adjustment model. This dynamic model is akin to the approach utilized in the earlier study by Berndt and Samaniego (1984). The partial adjustment model incorporates dynamics by considering the gradual adjustment of the system to changes over time. In the realm of theoretical modeling, Beenstock et al. (1999) have discussed nested and non-nested models. These distinctions in theoretical modeling provide a framework for considering the relationships among various elements in the model, allowing researchers to choose the most suitable approach based on the specific characteristics and complexities of the system under investigation. Beenstock et al. (1999) elucidate the concept of nested models, where consumers allocate resources for the consumption of competing goods after deciding on total consumption allocations. This approach mirrors the idea of "derived demand," indicating that the demand for one good is dependent on the demand for another. In contrast, non-nested models describe the simultaneous decision-making process of the consumer for all consumption goods, reflecting a "direct demand" approach. The distinction between nested and non-nested models provides insights into how consumer preferences and choices are structured, influencing the overall demand dynamics for various goods. In their study, Beenstock et al. (1999) have opted for the nested model, emphasizing the allocation of resources by consumers for competing goods after determining total consumption allocations. In a similar vein, Ghader et al. (2006) have employed a derived demand function, which conceptualizes the demand function as a system of equations, reflecting the interdependence of different goods in the consumption portfolio. This approach aligns with the notion that the demand for one good is derived from the demand for others, providing a comprehensive view of the interconnected dynamics in consumption patterns. As for Filippini (1999), further details or context would be needed to provide relevant information or insights.

The concept that electricity demand is derived demand implies that it can be delineated through production theory, which posits that economic agents require input factors for the production process. This relationship is embedded in both the cost and utility functions of the economic agent. Halvorsen (1976) holds the perspective that, within the household's utility function, electricity demand manifests as a form of direct demand. This dual characterization underscores the multifaceted nature of electricity demand, where it is not only a crucial input for production processes but also a direct and essential component of household utility preferences. Wilder and Willenborg (1975) expound on the notion that household electricity demand is a derived demand, intricately linked to the primary demand for electric stock. This primary demand encompasses appliances, electric services, and other electric devices. In this framework, household electricity consumption is considered a consequence of the demand for various electrically powered goods and services, reinforcing the idea that it is derived from the broader array of electrically dependent items within a household. According to Anderson (1973), the household's electricity demand is characterized as derived demand originating from its utility function. Beyond considerations of income and commodity costs, this approach incorporates a comprehensive spectrum of factors. Geographical, demographical, and social behaviors of the household are integral components within this framework. This perspective recognizes the intricate interplay of various elements that contribute to the derived demand for electricity, providing a more holistic understanding of the factors influencing household electricity consumption. Reiss and White (2005) conclude that household electricity is a derived demand, contingent upon the stock of electric appliances. The durability of these appliances plays a pivotal role in shaping both short and long-term demand. They base their analysis on the utility maximization theory of households. Synthesizing insights from the reviewed theoretical literature, it can be asserted that electricity demand inherently exhibits derived demand characteristics. Consequently, the application of a reduced form model is deemed useful for capturing the intricate dynamics of such derived demand relationships.

Certainly, the empirical work in the field of electricity demand literature showcases considerable diversity across various dimensions. Notably, there is a wide array of studies with differences in terms of electricity demand determinants, model specifications, estimation techniques, and even the outcomes obtained. This diversity underscores the complexity of the electricity demand landscape and the myriad factors influencing it. As researchers employ different methodologies and focus on various aspects, the empirical literature reflects the multifaceted nature of electricity demand and the need for tailored approaches to comprehend its intricacies comprehensively. As elucidated by Espey and Espey (2004), the economic literature on electricity demand exhibits substantial diversification across various dimensions, including economic theory, estimation techniques, model specifications, the nature of data, and outcomes. For instance, the price elasticity of electricity demand ranges from -0.076 to -2.01 in the short run and -0.07 to -2.5 in the long run. This variation underscores the complexity of the field. In addition to economic variables such as income, prices, and appliance usage, socioeconomic, demographic, geographic, and meteorological factors are identified as crucial determinants in the multifaceted process of electricity demand determination. Certainly, the impracticality of covering all deterministic aspects in electricity demand research is acknowledged, primarily due to limitations in knowledge and data accessibility. Estimation techniques in this field span a wide range, with a notable prevalence of cointegration and Error Correction Model (ECM) approaches, often implemented through Vector Autoregressive (VAR) models. These methods are favored for estimating long-run relations, short-run dynamics, and elasticities, aligning with the characteristics of electricity data.

The choice of econometric techniques, including cointegration and ECM approaches, not only enhances the reliability of results but also provides statistical plausibility. Nonetheless, it is emphasized that the nature of the data should be carefully considered before applying any estimation technique. This recognition underscores the importance of methodological diligence in ensuring the robustness and validity of empirical findings in the study of electricity demand. In the context of this specific study on the empirical analysis of electricity demand in Pakistan, it is imperative to delve into the literature related to Pakistan's electricity sector and demand. Recognizing that international studies highlight the significance of diverse outcomes contingent on the country and region, a focused exploration of Pakistan-specific literature becomes essential. The literature underscores the profound impact of rapid developments and technological innovations, fostering the widespread utilization of appliances. This surge in appliance usage is a key contributor to heightened energy consumption, encompassing electricity, oil, and gas, on a considerable scale. Understanding the nuances of these dynamics in the Pakistani context is crucial for formulating insightful and context-specific conclusions in the empirical analysis of electricity demand in the region. In recent years, Pakistan has experienced a persistent decline in the growth rate of electricity consumption, primarily attributable to the severe electricity crisis afflicting the nation. This crisis is compounded by escalating electricity prices, elevated income levels, constrained supply, and inadequate management practices. It is noteworthy that this study exclusively concentrates on the demand-side aspects of these challenges. The repercussions of these crises have significantly impacted socioeconomic progress and various sectors within the economy, underscoring the urgent need for comprehensive strategies to address the multifaceted issues surrounding electricity consumption in Pakistan. Hence, there is a critical need for an in-depth exploration of electricity demand issues to offer valuable, constructive, and practical recommendations for addressing and managing the prevailing electricity crisis. The scarcity of literature on energy and electricity demand in Pakistan accentuates the urgency of this research endeavor. Although there have been some efforts in the recent past, the existing body of work appears to be insufficient and inadequate. This study aims to fill this gap by building upon and expanding the insights derived from the limited existing literature, with the goal of providing more comprehensive and nuanced perspectives on the electricity demand challenges in Pakistan.

From the brief literature review on Pakistan, it can be deduced that electricity demand assumes a pivotal role in the formulation of policies. Consequently, a thorough examination of the demand side of the electricity sector becomes indispensable. The review of significant studies on electricity demand functions, both in the context of Pakistan and internationally, reveals a substantial diversity in estimation techniques and results. This diversity underscores the complex and multifaceted nature of electricity demand, emphasizing the need for nuanced and context-specific approaches to understand and address the challenges posed by variations in demand. The limited availability of research studies on electricity demand estimation in Pakistan underscores the necessity for more extensive exploration and investigation within both theoretical and experimental frameworks. The divergent results observed in different studies present challenges for the development of cohesive and unique policy formulations in the electricity sector. The existence of dissimilar findings highlights the complexity of the subject matter and emphasizes the need for further research to establish a more comprehensive understanding of the factors influencing electricity demand in the specific context of Pakistan. This ongoing exploration is crucial for informed decision-making and the development of effective and sustainable policies. Recognizing the sensitivity and significance of the issue at hand, this specific research study aims to ascertain the income and price elasticities in the context of electricity demand in Pakistan. By identifying the crucial determinants of electricity demand, the study seeks to contribute valuable insights that play a pivotal role in the derivation of electricity demand. This research opens a new paradigm for policy analysis concerning the management of electricity demand in Pakistan, providing a foundation for informed decision-making and the formulation of effective strategies to address the challenges in this critical sector. In following Table 1, results of some of the key studies about electricity demand at aggregate and disaggregate level (residential, industrial, commercial, and agriculture sectors) are stated.

3. RESEARCH METHODOLOGY

Indeed, theoretically, electricity demand is inherently derived demand, rooted in its dependence on the utilization of input factors within the production process. This conceptualization aligns with the foundations of "production theory," which posits that economic agents, whether households or firms, employ input equipment or stocks as integral components in their production processes. In this framework, the demand for electricity emerges as a consequence of the broader production activities within the economy, underscoring the interconnectedness between electricity consumption and the overall economic landscape. In the realm of electricity demand, economic agents utilize electricity consumption as an input factor in the production of commodities. This gives rise to derived demand, contributing to the agent's utility and cost functions. The intricacies of electricity demand are influenced by various factors, including the stock of electric goods, capital equipment, as well as demographic and geographic considerations. This dynamic interaction between electricity consumption, production processes, and the broader economic context highlights the multifaceted nature of electricity demand as a derived demand. Previous knowledge supports the understanding that electric appliances, income, and prices (both electricity and alternative sources) are influential fluctuation forces impacting electricity consumption. Additionally, demographic and geographic factors are recognized as having significant effects, contingent upon specific circumstances. This acknowledgment underscores the complexity of the determinants shaping electricity consumption, reflecting a combination of economic, technological, and contextual variables that contribute to the nuanced dynamics within the electricity demand framework. In the specific research study focusing on the empirical analysis of electricity demand in Pakistan, there is a recognition that electricity demand is sensitive to the prices of alternative fuels. It is apt to characterize alternative fuels, such as oil and gas, as complements to electricity. Across extensive regions, these fuels serve as crucial input factors for the generation of electricity, thereby establishing a complementary relationship between electricity demand and alternative fuel prices. This consideration adds a nuanced dimension to the understanding of the factors influencing electricity consumption in the Pakistani context.

Given the specific context of Pakistan, the demand function in this study will exclude alternative fuel prices, as they are not considered substitutes for electricity. Additionally, the focus of the study on annual data implies that temperature will not be incorporated in the analysis. Temperature, being a seasonal phenomenon, is outside the scope of this study, which aims to capture broader trends and determinants of electricity consumption over the annual timeframe. This targeted approach ensures a more focused and relevant analysis within the defined parameters of the research. The studies that have examined the impact of temperature typically utilize quarterly and high-frequency data. In contrast, this study employs annual time series data, which does not capture the seasonal fluctuations associated with temperature. Moreover, the primary objective of this study is to assess the influence of real income, prices, number of customers, and stock of electric appliances on electricity consumption. As a result, the demand function is articulated as follows

Electricity demand = f (real income, electricity prices, number of consumers, electric appliance)

In the empirical specification of the electricity demand model, studies such as those by Al-Faris (2002), Bose and Shukla (1999), De Vita et al. (2006), Galindo (2005), and others have adopted a double log-linear function of its determinants employing a "reduced form model". This particular specification is derived through utility maximization and cost minimization techniques. The double log-linear model yields elasticities, as emphasized by Varian (1988), which prove instrumental in demand management, analyzing demand behavior, electricity forecasting, and conducting policy analysis. The adoption of this model structure reflects a well-established approach in the literature for understanding and predicting electricity demand dynamics.

4. ESTIMATED RESULTS

The unit root test results displayed in Table 1 provide a foundational understanding of the time series properties of the variables influencing electricity demand in Pakistan, with disaggregation across aggregate, residential, and industrial sectors. The variables under consideration—electricity consumption, real income, electricity prices, number of consumers, and electric appliances—represent core determinants of electricity demand, as conceptualized in the specified functional form. Employing both Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests at levels (I(0)) and first differences (I(1)), the analysis evaluates whether these series are stationary or require differencing for further econometric modeling. Understanding the order of integration is critical before proceeding to cointegration or error correction modeling, as non-stationary data can lead to spurious regression results unless appropriately differenced or modeled through long-run equilibrium frameworks. Starting with the aggregate series, none of the variables exhibit stationarity at levels in either ADF or PP tests, confirming the presence of unit roots. Electricity consumption (Elect) has ADF and PP statistics of −1.814 and −0.788, respectively, well above conventional critical values, indicating non-stationarity at level. However, when differenced, both statistics become significantly negative (−3.665 and −4.406), confirming that the series becomes stationary after first differencing and is thus integrated of order one, I(1). This pattern repeats across the other aggregate variables—real income (Rincome), electricity price (Prelect), number of customers (Cust), and appliance usage (App)—which all transition from non-stationary at levels to stationary after first differencing. The stationarity of these variables at I(1) confirms the validity of proceeding to cointegration analysis to explore long-term equilibrium relationships among them. This is consistent with findings from other electricity demand studies in emerging economies, where macroeconomic indicators and sectoral electricity variables are typically found to follow unit root processes (Narayan & Smyth, 2005).

When the residential sub-sector is examined independently, a similar pattern emerges. Electricity consumption in the residential sector (Elect) has non-significant ADF and PP statistics at levels (−0.892 and −1.334), but becomes significant at first difference (−4.762 and −5.062), again indicating I(1) behavior. Real income, electricity price, number of customers, and appliance usage in this sector also follow a consistent I(1) pattern. These results confirm the robustness of the unit root behavior across different sub-sectoral disaggregations, supporting the notion that electricity demand drivers, though varying in magnitude across sectors, share similar stochastic properties. This homogeneity in integration order allows for uniform modeling strategies, such as applying Johansen cointegration tests across sectors without violating the stationarity preconditions (Jamil & Ahmad, 2011).

In the industrial sector, the behavior of the series again reflects non-stationarity at levels and stationarity at first difference. For example, industrial electricity consumption has ADF and PP values of −0.846 and −0.087 at level, but these become significant at first difference (−4.594 and −4.496). Interestingly, the number of customers (Cust) in the industrial sector shows the largest magnitude of differenced stationarity (ADF = −10.41; PP = −9.354), indicating particularly strong correction behavior in this series. This may reflect the industrial sector's responsiveness to shifts in electricity policy or market restructuring, where firm-level entry and exit dynamics can produce more volatile series, leading to faster stabilization when differenced. The strong stationarity of this variable may also suggest a relatively tight coupling between the number of active firms and industrial electricity usage, especially in an environment with targeted subsidies or regulated industrial tariffs (Siddiqui, 2004).

Table 1: Results of Unit root Test

Variables	Category	ADF I(0)	ADF I(1)	PP I(0)	PP I(1)
Elect	Aggregate	-1.814	-3.665	-0.788	-4.406
Rincome	Aggregate	-0.685	-4.814	-0.315	-5.031
Prelect	Aggregate	-2.648	-5.498	-2.693	-6.684
Cust	Aggregate	-0.251	-3.158	-0.394	-3.898
App	Aggregate	-2.301	-6.169	-2.578	-5.129
Elect	Residential	-0.892	-4.762	-1.334	-5.062
Rincome	Residential	-0.569	-5.681	-0.521	-6.15
Prelect	Residential	-1.862	-5.731	-2.159	-5.438
Cust	Residential	-1.306	-4.52	-1.405	-3.754
App	Residential	-2.091	-5.644	-2.548	-6.646
Elect	Industrial	-0.846	-4.594	-0.087	-4.496
Rincome	Industrial	-1.086	-5.484	-0.604	-6
Prelect	Industrial	-2.553	-4.572	-2.724	-6.161
Cust	Industrial	-1.418	-10.41	-1.612	-9.354
App	Industrial	-2.234	-6.883	-1.795	-5.043

Across all series and sub-sectors, the consistency of I(1) behavior provides important implications for model development. First, the uniformity of the integration order justifies the application of cointegration techniques such as the Johansen method or the Engle-Granger two-step procedure to estimate long-run relationships between electricity demand and its determinants. Second, the first differencing of non-stationary variables allows for the estimation of short-run dynamics via error correction models (ECMs), which are grounded in the theory of dynamic equilibrium adjustment and have been shown to be effective in modeling electricity demand in both developed and developing countries (Al-Faris, 2002). The reliability of these results is strengthened by the use of both ADF and PP tests. While the ADF test assumes a specific parametric correction for autocorrelation, the PP test uses non-parametric statistical adjustments to account for serial correlation and heteroskedasticity in the error terms. The agreement between these two tests across all series adds robustness to the conclusion that the variables are integrated of order one. This methodological rigor is vital in policy-oriented empirical research where modeling choices based on incorrect assumptions about stationarity could lead to misinformed decisions (Kebede et al., 2010).

From a policy perspective, the confirmation of unit roots across the variables suggests that shocks to electricity consumption, income, prices, or consumer demographics have persistent effects over time. For instance, a policy-induced price increase or an economic expansion would not only affect electricity demand in the short run but also shape long-term consumption patterns unless offset by structural adjustments. This finding emphasizes the importance of considering both transient and permanent components of electricity demand in policy analysis. Moreover, the non-stationary nature of appliance usage, particularly in the residential sector, indicates that trends in technology adoption and consumer behavior are deeply embedded and should be addressed through sustained energy efficiency programs rather than one-time interventions. The unit root test results provide strong empirical support for modeling electricity demand in Pakistan using time series techniques that accommodate I(1) behavior. The shared integration order across aggregate, residential, and industrial data sets facilitates a harmonized modeling framework capable of distinguishing between long-run equilibrium relationships and short-run fluctuations. This groundwork paves the way for a more nuanced exploration of electricity demand, accounting for structural differences across sectors while preserving consistency in econometric strategy.

The Johansen cointegration test results shown in Table 2 provide compelling evidence of long-run equilibrium relationships among the core variables influencing electricity demand across different economic sectors in Pakistan. This test, applied separately to aggregate, residential, industrial, commercial, and agricultural categories, evaluates whether non-stationary series—confirmed in previous unit root testing—move together in the long term. The presence of cointegration among electricity consumption, real income, electricity prices, number of consumers, and electric appliance usage underscores that despite short-run fluctuations, these variables exhibit stable long-term interactions that must be accounted for in policy and forecasting models. For the aggregate category, the trace statistic is 102.333, significantly exceeding both the 5% and 1% critical values (68.52 and 76.07, respectively). The associated eigenvalue of 0.592 confirms a strong and statistically meaningful long-run relationship among the variables at the macro level. This result validates the conceptual framework of electricity demand as a function of income, prices, consumer base, and appliance penetration. It also aligns with previous findings in the literature that highlight cointegration in national-level electricity demand models, especially in developing economies experiencing structural transformation and rising electrification rates (Shahbaz & Lean, 2012). The implication here is that electricity policy must be designed with a long-term perspective that accounts for the co-movement of economic and demographic variables, rather than relying solely on short-term consumption patterns.

The residential sector also demonstrates a robust cointegration relationship, with a trace statistic of 90.59 and an eigenvalue of 0.576, again surpassing the critical thresholds. This finding suggests that household electricity consumption in Pakistan is closely tied to long-term changes in income, pricing structures, and consumer characteristics. As income levels rise and urbanization deepens, residential energy demand is likely to increase in a predictable manner, modulated by appliance ownership and energy efficiency trends. The cointegration result here provides empirical justification for adopting dynamic pricing and energy conservation measures targeted at households. Such policies are especially relevant in contexts like Pakistan, where residential demand constitutes a major share of electricity usage and often strains grid reliability during peak periods (Kiani, 2013).

The industrial sector, with a trace statistic of 87.545 and an eigenvalue of 0.578, also exhibits significant cointegration among the selected variables. This is particularly important for a country where industrial growth is viewed as a key engine for economic development. The long-run relationship suggests that industrial electricity consumption is systematically influenced by economic activity, input prices, and firm-level energy demand characteristics. Policymakers must therefore recognize that disruptions in electricity supply or pricing will have enduring effects on industrial output and competitiveness. Moreover, the cointegration result implies that energy reforms targeting the industrial sector—such as efficiency incentives or tariff restructuring—can have lasting benefits if aligned with broader economic strategies (Farooq & Siddiqi, 2011).

In the commercial sector, the evidence of cointegration is even stronger, with a trace statistic of 119.131 and the highest eigenvalue in the table at 0.694. This sector's growing integration with electricity demand drivers reflects the rapid expansion of Pakistan's services sector, urban retail environments, and office-based economic activity. The strength of the cointegration relationship indicates that electricity consumption in the commercial domain is highly sensitive to macroeconomic and structural variables. Commercial buildings are becoming increasingly energy intensive due to rising demand for lighting, cooling, and ICT services. The presence of a long-term equilibrium relationship suggests that demand-side management programs, green building codes, and investment in energy-efficient technologies could yield sustained benefits in this sector. These findings are consistent with global evidence showing that the commercial sector is often more responsive to economic signals than either residential or industrial segments, due to its exposure to energy cost pass-through and productivity incentives (Al-Shaikh & Shahbaz, 2015).

The agricultural sector, often overlooked in energy policy debates, also exhibits cointegration with a trace statistic of 75.892 and an eigenvalue of 0.49. While lower than other sectors, these values still surpass the critical thresholds, indicating a statistically significant long-term relationship among the variables. Agriculture in Pakistan remains heavily dependent on electric-powered tube wells and mechanized irrigation, particularly in canal-fed regions where groundwater extraction supplements surface water. This result confirms that electricity usage in agriculture is not purely exogenous or policy-driven but closely linked to income levels, equipment usage, and broader rural economic dynamics. The cointegration finding supports the inclusion of agriculture in national energy planning, especially in the design of targeted subsidies, load management strategies, and solar pump integration programs, which aim to optimize energy consumption without compromising food security (Malik et al., 2010). The cointegration findings justify the use of vector error correction models (VECMs) in subsequent analyses, which can capture both short-run dynamics and long-run equilibrium adjustments. From a methodological standpoint, the consistency of cointegration across sectors reinforces the robustness of the underlying theoretical model and the reliability of the data. From a policy perspective, these findings emphasize that energy reforms must be tailored not only to address immediate supply-demand imbalances but also to recognize the persistent and interconnected nature of electricity usage within the broader economic system.

The long-run elasticity estimates presented in Table 3 offer critical insights into the persistent determinants of electricity demand across various economic sectors in Pakistan. By disaggregating elasticities across aggregate, residential, industrial, commercial, and agricultural segments, the analysis allows for a granular understanding of how electricity consumption responds to shifts in real income, electricity prices, the number of consumers, and appliance ownership over extended periods. These long-run elasticities are particularly valuable for forecasting future energy needs and guiding the design of sector-specific energy policies, infrastructure investments, and pricing reforms. In the aggregate category, the elasticity of electricity demand with respect to real income is 0.261, indicating a relatively inelastic but positive long-term relationship. This suggests that a 1 percent increase in real income would lead to a 0.261 percent rise in electricity demand at the national level. While the elasticity is less than unity, it still confirms that economic growth contributes to higher electricity consumption, albeit at a moderate rate. This is consistent with economic theory and previous empirical findings in emerging economies, where electricity demand rises with income, but not proportionally, due to saturation effects and gradual efficiency improvements over time (Narayan et al., 2007). The price elasticity of electricity at the aggregate level is estimated at −0.956, approaching unitary elasticity in absolute terms. This indicates that electricity demand is quite sensitive to price changes in the long run. A 1 percent rise in electricity price would reduce electricity consumption by nearly 0.96 percent, suggesting that price-based interventions could be effective in managing demand, especially if combined with targeted subsidies or tiered pricing for low-income households.

Table 2: Johansen Cointegration Test

Category	Eigenvalue	Trace Statistics	5% Critical Value	1% Critical Value
Aggregate	0.592	102.333	68.52	76.07
Residential	0.576	90.59	68.52	76.07
Industrial	0.578	87.545	68.52	76.07
Commercial	0.694	119.131	68.52	76.07
Agriculture	0.49	75.892	68.52	76.07

The elasticity of demand with respect to the number of customers (0.071) is modest but positive, implying that as the consumer base expands, total electricity consumption increases slightly. However, this elasticity is significantly lower than other variables, which could reflect the slow pace of electrification or minimal per-customer consumption increases at the margin. The elasticity with respect to appliance usage (0.655) is more substantial, underscoring the strong influence of household and commercial appliance penetration on national electricity consumption. The proliferation of air conditioners, refrigerators, and entertainment devices continues to drive up electricity demand, particularly in urban regions. These findings reinforce the need for appliance standards and energy labeling programs to promote the adoption of energy-efficient technologies (Filippini & Pachauri, 2004). The residential sector elasticities are not fully reported in the table, yet the constant term of 6.017 suggests a high base level of electricity demand in this segment, reflecting both basic consumption needs and growing urbanization. While the table omits the long-run coefficients for income, price, customers, and appliances in this sector, findings from the other sectors can offer some interpretive parallels. Historically, residential electricity demand tends to be more responsive to changes in appliance ownership and moderately responsive to income, given that much of household energy consumption is discretionary and influenced by lifestyle choices (Sa'ad, 2009).

In the industrial sector, income elasticity is 2.938, indicating that electricity demand is highly elastic with respect to economic activity. A 1 percent increase in industrial output is associated with a nearly 3 percent increase in electricity use. This suggests that electricity is a vital input in Pakistan's industrial production processes, and demand is likely to grow rapidly as industrialization intensifies. The price elasticity in the industrial sector is −1.894, which is relatively high in magnitude. This implies that industrial electricity demand is highly responsive to price changes, likely due to cost optimization strategies and energy management systems within firms. The elasticity for the number of customers is −0.072, indicating a slight negative association. This could reflect firm consolidation or greater efficiency among existing industrial users as the consumer base grows. The appliance elasticity of 0.35, while positive, is lower than in other sectors, possibly due to standardized industrial equipment that has less variation in energy consumption compared to household appliances.

Table 3: Long Run Elasticities

Variables	Aggregate	Residential	Industrial	Commercial	Agricultural
Constant	3.09	6.017	5.341	2.366	14.939
Rincome	0.261		2.938	1.125	0.525
Prelect	-0.956		-1.894	-0.577	-1.725
Cust	0.071		-0.072	-1.573	0.526
App	0.655		0.35	0.255	1.94

In the commercial sector, the income elasticity is 1.125, suggesting that electricity use grows proportionally with commercial sector income or activity levels. This elasticity supports the argument that economic expansion in services and retail sectors drives substantial increases in energy demand. The price elasticity of −0.577 indicates moderate sensitivity, reflecting the commercial sector's limited ability to pass costs onto consumers or adopt immediate substitutions. The number of customers has a large negative elasticity of −1.573, which may seem counterintuitive. This could suggest that as the number of small commercial units increases, total electricity consumption per unit decreases, possibly due to lower per-customer usage or the increasing prevalence of informal sector businesses with limited electricity access. The appliance elasticity of 0.255, though positive, is moderate, reflecting the role of devices such as lighting, air conditioning, and computers in commercial electricity usage, which tend to scale with economic expansion (Dergiades et al., 2013).

The agricultural sector demonstrates distinctive dynamics, with an income elasticity of 0.525, suggesting a moderately elastic response to rural income growth. As farmers experience higher income levels, their electricity consumption rises, likely due to increased use of electric irrigation pumps and post-harvest processing equipment. The price elasticity of −1.725 is particularly noteworthy, indicating that agricultural electricity demand is highly sensitive to changes in price. This finding aligns with the sector's historical reliance on subsidized electricity tariffs, which, when removed or adjusted, can significantly alter usage patterns. The number of customers elasticity (0.526) is similar in magnitude to that of income, pointing to the expansion of electrified rural areas as a major driver of total electricity consumption. Notably, the appliance elasticity of 1.94 is the highest among all sectors, suggesting that as farms adopt electric-powered tools, irrigation systems, and storage equipment, energy usage increases substantially. This has important implications for rural energy policy, particularly regarding the promotion of energy-efficient agricultural technologies and solar-powered alternatives (Khattak et al., 2012). The long-run elasticities across all sectors indicate that electricity demand in Pakistan is influenced by both economic and structural factors in varying degrees. While income and appliance usage generally drive up demand, electricity prices serve as an effective tool for managing consumption in the long term, particularly in industrial and agricultural sectors. Expanding the consumer base appears to contribute modestly to aggregate demand but has sector-specific implications that may differ based on usage profiles and infrastructure access. These elasticities offer valuable guidance for policymakers aiming to balance electricity supply and demand through pricing, infrastructure expansion, and energy efficiency programs.

The estimates reported in Table 4 from the Vector Error Correction Model (VECM) offer a detailed overview of the short-run dynamics and the adjustment process toward long-run equilibrium in electricity demand across key economic sectors in Pakistan. The inclusion of first-differenced variables, such as changes in electricity consumption, real income, electricity prices, number of consumers, and appliance usage, allows for the examination of short-run responsiveness, while the error correction term (ECT) captures the speed at which each sector reverts to its long-term equilibrium following a shock. This structure is particularly relevant in a volatile energy environment where both demand-side fluctuations and policy shifts frequently disrupt equilibrium conditions. In the aggregate model, the coefficient of the lagged change in electricity consumption (ΔElect(-1)) is 0.195, indicating a positive but modest level of short-run inertia. This suggests that previous changes in electricity consumption contribute to current fluctuations, although the magnitude is not large enough to signify strong self-reinforcing behavior. The coefficient on lagged real income change (Δrincome(-1)) is 0.284, highlighting the fact that changes in income continue to exert a meaningful impact on electricity consumption in the short run. The corresponding negative coefficient on electricity prices (Δprelect(-1)) at −0.222 aligns with expectations: increases in electricity prices result in reduced consumption even in the short term, suggesting that price signals are effective in altering consumption patterns. The coefficients for changes in the number of consumers and appliance ownership (0.237 and 0.031 respectively) further reinforce the influence of structural factors on electricity demand, although the small magnitude of the appliance coefficient indicates that the effects of new appliance adoption are more pronounced over the long run. The error correction term (−0.559) is negative and significant, implying that approximately 56 percent of the disequilibrium is corrected each period, confirming the system's strong tendency to return to its long-run path. This aligns with prior findings that energy consumption at the macro level tends to self-correct efficiently over time (Zachariadis & Pashourtidou, 2007).

In the residential sector, the short-run adjustment appears to be more volatile. The coefficient on lagged electricity consumption is higher at 0.423, indicating a stronger short-run autoregressive component. This suggests that recent increases in residential electricity use have a greater tendency to influence subsequent consumption behavior, likely due to behavioral habits and consistent appliance usage. The response to income changes is slightly lower than in the aggregate model, at 0.188, reflecting the fact that household energy expenditures may be somewhat shielded from short-term income variability, particularly in urban settings where electricity is viewed as a basic necessity. The price elasticity of −0.369 suggests that residential consumers are relatively responsive to price changes in the short run, possibly due to billing feedback, load-shedding schedules, or tariff adjustments. This level of responsiveness is encouraging for policymakers seeking to use pricing mechanisms as a tool for demand management. The effect of changes in consumer base (0.061) and appliances (0.282) is also noteworthy, especially the latter, which reflects the significant role of appliance adoption in shaping household electricity use. The error correction term of −0.198 shows that only 19.8 percent of deviations from long-run equilibrium are corrected in each period, indicating a slower adjustment process in the residential sector. This lag may be due to consumer stickiness or structural limitations in changing consumption behavior rapidly (Bernstein & Griffin, 2005).

In the industrial sector, the short-run dynamics are dominated by a substantial coefficient on the number of consumers (1.934), suggesting that changes in the number of industrial electricity consumers exert a strong influence on overall consumption. This could reflect expansion in manufacturing activity or entry of energy-intensive firms. The influence of lagged electricity consumption is also high (0.443), signaling that past consumption is a reliable predictor of near-term usage, possibly due to stable production cycles. The short-run responsiveness to income is relatively modest at 0.063, which may reflect the decoupling of industrial output from short-term income variations. Price elasticity (−0.244) remains in line with expectations, showing that higher prices depress consumption, although not excessively. The appliance coefficient is small (0.026), likely because industrial electricity use is driven by heavy machinery and equipment that do not fluctuate frequently. The ECT of −0.331 confirms a reasonably fast adjustment to long-run equilibrium, with 33.1 percent of the gap being closed each period. This supports the idea that electricity usage in industry is responsive not just to economic factors but also to structural alignment over time (Menyah & Wolde-Rufael, 2010).

In the commercial sector, the coefficient on ΔElect(-1) is 0.296, again showing a relatively strong autoregressive behavior. The short-run impact of income is negligible (0.001), which is somewhat surprising but may reflect the short-term inelasticity of electricity use in office buildings, retail spaces, and service establishments. On the other hand, electricity price remains an influential factor, with a coefficient of −0.262, suggesting that even modest price shifts can lead to reductions in commercial energy use. The number of consumers exerts a sizeable impact at 0.626, possibly due to the dynamic nature of commercial development and expansion in urban centers. The appliance effect is also positive (0.073), as equipment like lighting systems, air conditioning units, and point-of-sale systems contribute to the variability in energy use. The ECT for the commercial sector is −0.266, reflecting a moderate adjustment rate back to equilibrium. This suggests that while the commercial sector is reactive in the short term, structural changes also drive convergence in the long run (De Vita et al., 2006).

The agricultural sector shows some distinct behavior. The only negative coefficient for ΔElect(-1) appears here (−0.035), suggesting that changes in past electricity usage have a negligible or even inverse short-run effect. This might reflect seasonal variations, irrigation timing, or exogenous factors like rainfall patterns. The impact of income on electricity demand is strongest in this sector (0.859), confirming that short-run variations in rural income directly affect electricity usage, likely through water pumping, crop processing, and cold storage activities. Price sensitivity is more moderate at −0.157, suggesting that agricultural consumers are somewhat shielded from price signals, potentially due to subsidized tariffs or irregular billing. The effect of new customers (0.4) is significant, highlighting the ongoing expansion of electrification in rural areas. Appliance impact is minimal at 0.003, consistent with limited technological variability in rural agricultural equipment. The error correction term at −0.499 indicates that 49.9 percent of disequilibrium is corrected in each period, suggesting a relatively fast reversion to long-run equilibrium. This is likely facilitated by the centralized planning and policy mechanisms that govern electricity allocation in agriculture (Kiani, 2013).

Together, these results confirm the heterogeneous nature of electricity demand across sectors in Pakistan. While some sectors, such as industry and agriculture, adjust relatively quickly to long-run equilibrium, others—most notably the residential sector—exhibit slower correction speeds. Income and price remain dominant explanatory variables across all sectors, but their short-run effects vary considerably. The findings also highlight the critical role of consumer growth and appliance adoption, especially in the commercial and residential domains. Policymakers seeking to balance electricity demand and infrastructure planning must tailor their interventions to these sectoral dynamics, combining economic incentives with structural reforms to ensure both short-run responsiveness and long-run stability.

Table 4: Vector Error Correction Model and Short Run Dynamics

Variables	Aggregate	Residential	Industrial	Commercial	Agricultural
ΔElect (-1)	0.195	0.423	0.443	0.296	-0.035
Constant	0.009	0.058	0.023	-0.02	0.089
Δrincome (-1)	0.284	0.188	0.063	0.001	0.859
Δprelect (-1)	-0.222	-0.369	-0.244	-0.262	-0.157
ΔCust (-1)	0.237	0.061	1.934	0.626	0.4
ΔApp (-1)	0.031	0.282	0.026	0.073	0.003
ECT	-0.559	-0.198	-0.331	-0.266	-0.499

5. CONCLUSION

In conclusion, the study provides valuable insights into the dynamics of electricity demand in Pakistan, particularly highlighting the severe consequences of the ongoing electricity crisis on the economy. The results confirm the existence of unit root problems, necessitating the application of cointegration tests to establish long-run associations among electricity demand and its determinants. The findings underscore the widespread impact of the electricity crisis on industries, exports, and employment, leading to substantial economic losses. The error correction model reveals significant values for the adjustment parameter in all sectors, indicating a convergence towards equilibrium after fluctuations. However, the speed of adjustment varies across sectors, with the aggregate sector demonstrating a higher adjustment speed. Short and long-run elasticities analysis reveals that, in the short run, electricity demand is inelastic with respect to income and prices, suggesting that people consider electricity a necessity. Long-run elasticities vary across sectors, with income elasticity greater than unity in most cases, justifying electricity as a luxury good due to a significant portion of the population lacking access to electricity. The study provides crucial policy implications, emphasizing the need for tailored demand management policies for each sector. Long-run elasticity results suggest that a decrease in prices is the best response in residential and agriculture sectors, while increasing prices is effective in aggregate and industrial sectors. Short-run policies should focus on significant price increases to curb demand. Additionally, the study recommends unique demand management and group pricing policies for each sector, highlighting the importance of implementing peak-load pricing to manage electricity consumption during peak hours. Furthermore, the study calls for a review of policies that rapidly increased the supply of electric appliances at a cheaper rate, considering their significant influence on electricity consumption. It suggests that the government needs to invest in new energy-generating plants and infrastructure, encourage private sector participation to enhance competition, and introduce cleaner and cheaper substitutes for electricity. Finally, the implementation of energy and electricity conservation strategies across all sectors is advocated for effective and sustainable resource utilization.

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