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HARNESSING POWER FOR PROGRESS: ANALYSING PAKISTAN'S ELECTRIC TRANSMISSION SECTOR, ITS ROLE IN ENERGY SECURITY AND ECONOMIC STABILITY (2018–2023)

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ABSTRACT

This paper examines the role of Pakistan's electric transmission sector in ensuring energy security, driving economic stability and supporting national security from 2018 to 2023. Employing a convergent mixed-methods design, the study integrates qualitative insights from interviews and surveys with quantitative data from field observations, NEPRA (National Electric Power Regulatory Authority) reports and case studies. The findings reveal that inefficiencies within the transmission sector, including high transmission and distribution (T&D) losses, technical issues, aging infrastructure and governance challenges, have far-reaching implications for the country's energy and economic landscapes. Quantitative analysis shows that T&D losses consistently exceed 18% annually, resulting in substantial financial losses and contributing to the circular debt crisis, which has surpassed PKR 2.3 trillion. Qualitative insights from experts and policymakers highlight operational bottlenecks, inadequate investments and policy ambiguities as persistent barriers to improvement. These inefficiencies disrupt energy supply, deter industrial growth and escalate production costs, leading to reduced GDP growth and diminished export competitiveness. The paper also identifies the critical role of the transmission sector in national security and geopolitical tensions. Proposed strategies include modernizing infrastructure, integrating renewable energy sources, implementing advanced metering technologies and introducing governance reforms.

Keywords:*Energy Security, Economic Security, Sustainable Growth, Peace and Prosperity, Energy Policy*

Introduction

In global power politics, energy is becoming more and more a strategic instrument and strategic weapon as nations use energy resources and infrastructures as means of coercion towards the achievement of geopolitical ends. Energy producing states with regional power often manipulate energy supply chains such as oil, gas and electric power as leverage to shape policies and actions of energy dependent states. Energy embargoes, pricing manipulations and selectively shutting down the electricity line are among the tools of economic and political pressure. Energy has been central to global power dynamics, from OPEC's 1973 oil embargo to more recently Russia's control over Europe's gas supplies as tensions between Ukraine and Russia escalate. These two events show and prove that energy is not a domestic issue; it is a major component of international relations and geopolitical strategies. Energy is considered a critical factor capable fostering the national security and national resilience; therefore, securing the energy necessitates a state-centric and human-centric security approach.

Given its location at the intersection of energy importing and transit states (Turkmenistan–Afghanistan–Pakistan–India natural gas pipeline TAPI; Central Asia–South Asia power contract CASA–1000 involving Tajikistan–Afghanistan–Pakistan), for Pakistan energy is not just an internal affair, but also a factor that melds its geopolitical standing. This reveals the balancing act with cooperation on energy electricity and petroleum with Arab countries and China, an international cooperation that it should rely on. In South Asia's complex security environment, a secure and resilient energy sector is thus necessary not only as an augury for mitigating internal vulnerabilities but also including to address external coercion and to ensure sovereignty and regional influence.

The basis of the international relations theory is the theoretical framework developed by Prof. Barry Buzan in his book People, States, and Fear (1991). As critical dimensions required for a state's survival, Buzan argued that the Political, Military, Societal, Economic, and Environmental sectors should be understood. These are diverse but interrelated areas where the possibility of new threats for national security rise. The impact of energy security ranges from being an all-embracing component from the five sectors of security framework provided by Buzan. Additionally, frames how issues are securitized as existential threats that demand exceptional measures from the state through the lens of Buzan's Securitization Theory coin novated by Ole

Wæver in the Copenhagen School. In the realm of energy security, securitization is the act of representing energy vulnerabilities (e.g., dependence on imports, sabotage of infrastructure, or climate risks) as urgent threats which warrant an alteration of norms, the influx of greater investment, or even military protection of resources.

In Pakistan, over the years energy has been securitized due to persistent crises, lack of capacity, low availability, high cost of electric energy adversely affecting domestic and industrial sectors including circular debt crisis, reliance on imports, major dependence on clean sources of generation of electricity such as hydropower or solar or wind projects which are vulnerable to climatic shifts. Energy challenges have been framed as Existential threats to national security, stability and national resilience causing action such as, infrastructure investment under CPEC and, renewable energy adoption (etc.) According to Buzan's framework, this securitization fits in as issues are prioritized around the time that survival is perceived to be at stake. This therefore, is a strategic initiative that not only responds to internal challenges but also complementing efforts at balancing South Asia's regional power dynamics on which major military powers close to one another possess cutting edge conventional and nuclear arsenals and continue to be trapped in a perpetual state of security dilemma.

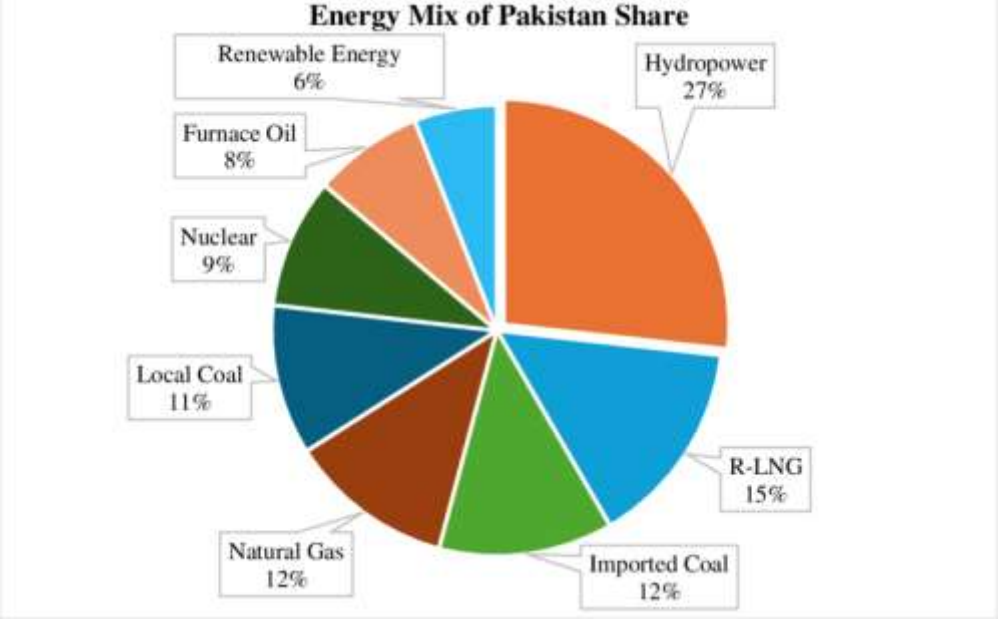

Fig 1. Pakistan's Energy Mix. Source: Design and development of geothermal-based cooling system for human comfort. Asian Journal of Science, Engineering and Technology (AJSET).

The state efforts for Pakistan's energy security domain are aimed at expanding its national capacity to support the growing domestic and industrial demands and to compete with the national and international markets, by striving the uninterrupted and cost-effective power supply. Long struggling in the field of electric energy, Pakistan is busy in strengthening its energy security in the domain of electric energy through international partners, primarily China, for developing infrastructure projects such as dams, wind and solar energy installations and crucial upgrades in exiting electric energy structure.

In this work by Prof. Russell L. Ackoff was written in 1974, 'Redesigning the future', and in which he states that 'In fact, we have also come to realize that no problem ever exists in complete isolation.' Each problem 'touches' other problems and so is part of a set of 'interrelated problems." Pakistan primarily dependent on hydel power for its electric energy generation is confronted with the most difficult challenges as dwindling hydel sources on account of many regional and environmental reasons have jeopardized its electrical energy security. Such valuable electrical energy reduction and losses is bringing state multifaced challenges. The domestic and industrial sectors are adversely affected by these challenges, whose main element includes their limited capacity, inadequate availability and high transmission and dispatch losses resulting in high-cost electric energy. These challenges together with supply and demand, high cost has further aggravated the circular debt crisis of Pakistan. The figure below explicitly shows that this circular debt is tied to broader economic instability and strategic vulnerabilities for Pakistan.

Solving these challenges demands further insight into what makes systems vulnerable at the root and to optimize the appropriate mitigation measures. Electric energy systems in Pakistan have an interdependent structure that can result in one's problem cascading to the entire system. Transmission systems are central to energy security but often underappreciated in wider discussions, and are critical areas for resilience and reliability to focus on, as they are the ultimate link between generation and distribution. But this resilience is yet to be prevalent in Pakistan due to the transmission sector challenges that the current power system experiences. The electric transmission segment belongs to a substantial part of the energy sector and this research is related to the challenges faced by the Pakistan economy over the electric transmission sector referent

object is Pakistan electric transmission sector (Pakistan: from 2018 to 2023).

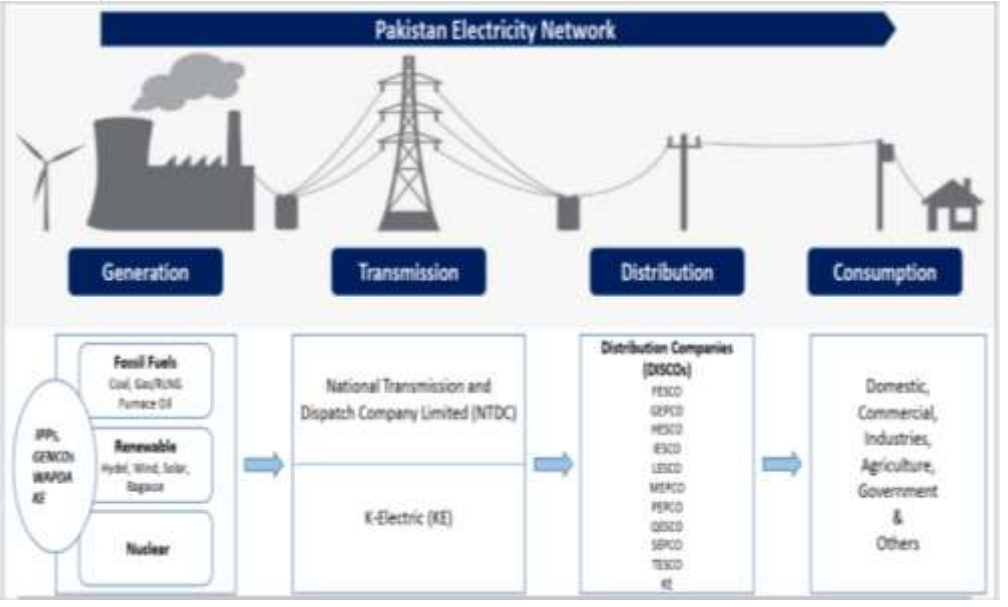

Fig 2. The Pakistan Electrical Energy Segment Overview.

Reliance by Pakistan on China for electricity infrastructure development largely through CPEC energy projects such Sindh, Punjab and Baluchistan Wind and Solar Power projects), and on Arab countries for the imports of oil and gas further magnifies these challenges to Pakistan's economic security. These dependencies not only swell foreign exchange pressures but also determine trade relations that pull destination fiscal stability and national sovereignty out. But Pakistan's trade deficit continues to mount from rising energy import bills paid in dollars, further hobbled its economic resilience. It also has such dependencies that constrain Pakistan's geopolitical autonomy and makes the country fall in the complex relationships with its energy partners while Pakistan struggles to fulfill its internal energy requirements.

Understanding the vulnerabilities present in Pakistan's electric transmission sector is key to understanding the country's energy security challenges. Being crucial, the transmission sector suffers from systemic inefficiencies limiting its performance and hence runs at greater risks to national resilience and security. The challenges in transmission and dispatch segments have lost around 500 billion rupees over the past five years, contributing to the 2.3 trillion-rupee circular debt crisis means losing 3,500 gigawatt hours of energy. Prof. Berry Buzan expatiates on blackouts as social sector's dimension of security due to these losses containing to

economic activities taking long times in critical sector like healthcare and industry for instance.

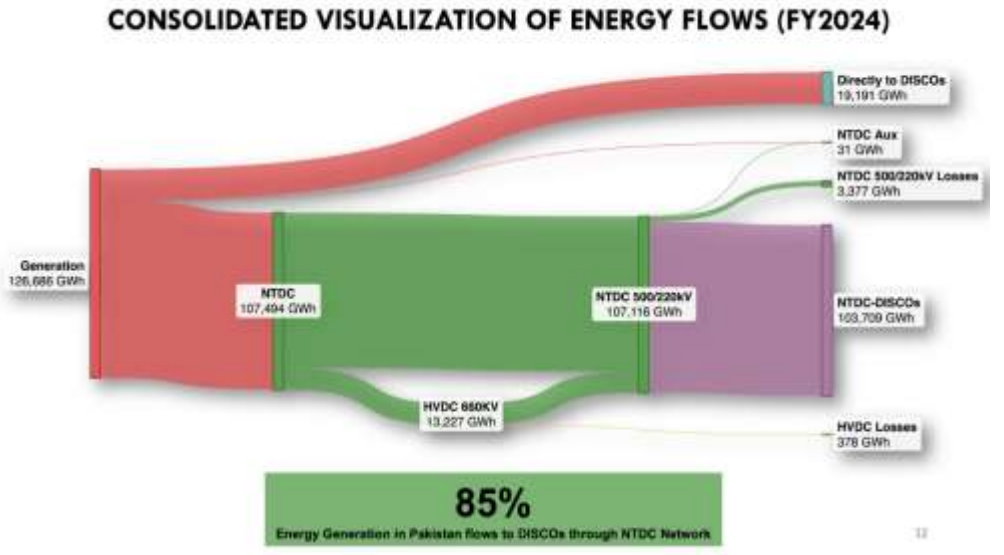

Fig 3. The line flows of Pakistan Electrical energy.

Such inefficiencies increase Pakistan's heavy dependence on costly energy imports, and on technological solutions such as generators and solar panels. These needs force the country into a cycle of IMF, World Bank and international financial institutions terms and conditions and further entrench the cycle of dependency. Energy losses and transmission inefficiencies must therefore be reduced not only to improve economic stability, but also to enhance national security and resilience.

R. L. Ackoff Redesigning the future, 1974 p. further. 20. Problems never come alone space and time-wise and they are surrounded by other problems. "The more a scientist knows about the context of the problem, the higher his chances for finding a truly adequate solution". The challenges of electric transmission sector result from several factors such as aging of infrastructure, poor maintenance, substandard quality of material, and climatic conditions. Theses challenges are exacerbated by societal implications such as theft and vandalism and vulnerabilities caused by physical security incident. A nationwide, nearly 24-hour blackout was caused by a single transmission failure at the Guddu power plant in Sindh. The country's operations got crippled by such an event; which only goes to show that even a single tripping event can render the country to a standstill. In the modern battle field, these weaknesses provide strategic opportunities for adversaries, transforming disruptions of the energy sector into game changing advantages in military conflicts as articulated by

Prof Berry Buzan in his Military sector of the Framework. This represents the ugly realities of how vulnerabilities of the energy sector directly impact Pakistan's national security posture in the face of internal and external threats.

The purpose of this paper is to unearth the part of electrical transmission system in supplying Pakistan's economic division and evaluating the causes igniting the problems related to this segment. Actionable insights for policymakers to resolve the identified challenges are derived from the study. Through an integrated approach based on a holistic perspective drawn from complementary subjects, this study analyses the role of transmission sector in economic dimension of the country using a holistic framework that considers transmission systems as an interconnected system, not as a group of isolated components. The establishment of a stable energy foundation for Pakistan is the contribution of this paper. In the end, it will help the country to secure the more balanced and secures regional position in South Asia.

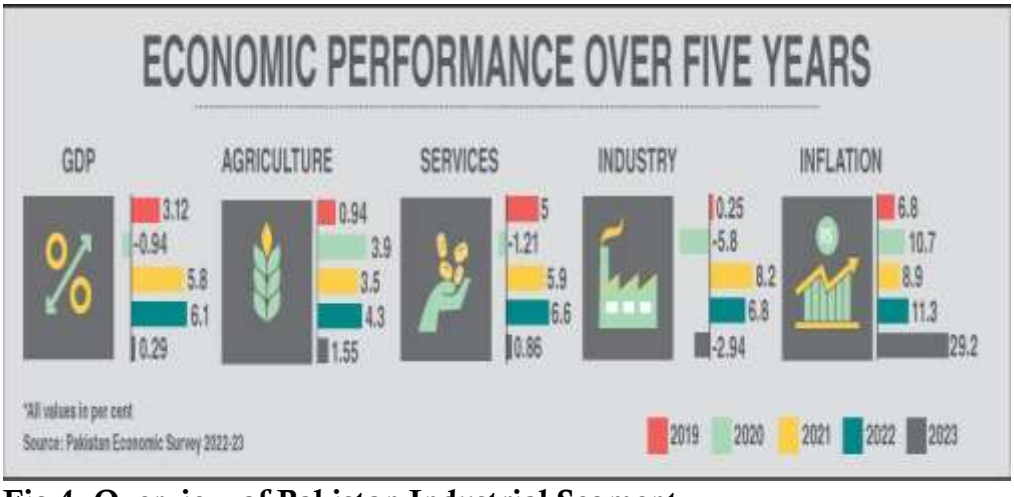

Fig 4. Overview of Pakistan Industrial Segment

Additionally, an attempt is made to propose the actionable strategies for reducing the transmission and dispatch losses, alleviating the problem of circular debt and improving the reliability and resilience of Pakistan's energy systems. Lastly, this paper intends to offer policymakers, energy sector planners and other stakeholders a comprehensive framework with which to evaluate vulnerability in other elements of critical infrastructure, such as oil and gas, renewable energies and other non-POL energy sources. It aims to enhance such discourses in security and strategy and in so doing contribute to Pakistan's energy security, economic stability and national security posture as a case study whose

lessons have relevance for others dealing with analogous difficulties.

LITERATURE REVIEW

An important issue of energy security has been increasingly considered as a key to the national and regional stability. It is more than ensuring reliable availability of energy resources, but also control of energy transportation infrastructure and the affordability of energy services. Not only is energy security imperative for economic stability, but also for political sovereignty and social resilience (Fîţă & Grigorie 2021, Abbas & Alqama (2020). Energy security took global toil during 1973 oil crisis which brought to the fore, how dependent are Nations to energy disruptions and how the energy access is interwoven with the national security (Kurian & Vinodan, 2013; Cherp et al., 2012). Since then, it new included different dimensions such as environmental sustainability, technological innovation and social well being which have a positive impact on the resilience of a state against internal and external shocks (Mara et al., 2022).

For developing countries, energy security is particularly important, as their challenges are unique to their rapid industrialization, high energy demand and insufficient infrastructure. The challenges exemplified by the foregoing section are obvious in Pakistan, a developing country in South Asia. Although it is dependent on imports as much as the energy imports (oil, gas) making it vulnerable to global prices fluctuations and supply disruptions (Kaygusuz et al., 2015; Krishnan, 2016). The country's dependence on hydropower currently makes up 85% of the country's electricity generation and adds to Pakistan's energy security concerns. As a result, Pakistan is especially vulnerable to the effects of climate change, including the change in rainfall patterns, increase in temperature, and extreme weather events, with which disrupt the production of hydropower (Burillo, 2018; Fant et al., 2020).

The climate of energy insecurity in Pakistan is further aggravated by the inefficiencies in country's electric power transmission and distribution (T&D) systems. These T&D networks are prone to high technical losses, inadequate maintenance, outdated infrastructure and lead to huge energy losses, power outages and high costs for the consumers. Ideally, these challenges directly contribute to Pakistan's circular debt crisis whose meaning is that embedded financial deficits make it harder [to] run the energy sector (Malik et al., 2019; Ayoo, 2020). Energy shortage in such case has enormous economic implications, as energy shortage hampers industrial output and regular activities, hampering the country economic stability and security (Sarangi et al., 2019).

Pakistan's energy sector faces not just technical challenges, but physical security threats as well. As such, power lines and substations are becoming more vulnerable to attack, vandalism and sabotage, resulting in long power outages. Jing Xie et al. (2014) and Sadeghian et al. (2022) have done the research that shows how attacks on energy infrastructure not only disrupt the energy supply of the country but also raise serious national security challenges. These vulnerabilities make Pakistan more vulnerable, particularly in times of geopolitical tension or natural disasters when consistent energy supply is essential for national defense and operation to recover.

In addition, Pakistan's climate change worsens its energy security risks. Burillo (2018) and Fant et al. (2020) share evidence that climate induced disruptions to energy production, especially hydropower, are becoming more likely given expected shifts in precipitation and water availability. The energy grid becomes notably more fragile facing demand during extreme events, and is further destabilized by rising sea levels, extreme heatwaves, and changing weather patterns (World Bank, 2022).

In light of these vulnerabilities, Pakistan has started searching for renewable energy sources like solar and wind. These renewable sources are an integrated essential for diversification of Pakistan's energy mix and for moving towards less dependency on imported fuels. But infrastructure limitations, financing constraints, technological innovation investment constraints, and regulatory rigidity can undercut that growth (Tziogas and Georgiadis, 2015; Shaikh et al., 2020). Ayoo (2020) states that Pakistan's energy transition is even more difficult due to the need for substantive grid modernization and energy storage solutions for mitigation of the variability of renewable energy sources.

Energy security in Pakistan is equally linked to the country's geopolitical position. Pakistan's membership in regional energy projects, including Turkmenistan-Afghanistan–Pakistan–India (TAPI), and Central Asia–South Asia (CASA-1000) power transmission agreement has underlined the importance of energy being a strategic component in Pakistan. These projects have the potential to diversify Pakistan energy supply, but they may expose Pakistan to geopolitical risks associated with political instability in adjacent countries (Shebonti & Dadwal, 2017; Kamran, 2019). Additionally, Pakistan depends on foreign energy infrastructure and investments creating dependencies which could limit its energy sovereignty and strategic autonomy (Riaz Ahmad et al., 2020).

The perspectives on energy security have since expanded to a multidimensional understanding that extends beyond the supply issue and includes elements such social, environmental and political. The definition of energy security proposed by Yao & Chang (2014) and Cherp & Jewell (2014) is expanded to align with issues such as energy equity, social impacts, and the imperative of a sustainable energy transition in response to climate change. These viewpoints stress the interdependence of energy systems and the importance of cross border collaboration to deal with common energy security issues.

On the horizon, long term energy security through renewable energy is an area of focus. The shift for mitigating carbon emissions and reversing impacts of climate change has raised awareness for renewable energy (RE), energy efficiency (EE) and technology innovation (TI) as the core pillars for energy security (ISES, 2017; IEA, 2017b; Tziogas & Georgiadis, 2015; Ayoo, 2020). Integrating renewable energy into its energy grid not only improves energy security but it also minimizes Pakistan becoming a dependent country to meet its energy demand, vulnerable and exposed to external geopolitical shocks and environmental risks (Fahad et al., 2020).

Due to the multifaceted nature of the problem, Pakistan's solution to its energy security challenge must also be multidimensional, namely addressing technical, environmental, political and economic dimensions. Long term energy security requires a holistic, integrated approach, including improvements in transmission infrastructure, a diversified energy mix, increased energy efficiency and protection of energy assets from both physical and environmental threats. Solutions to these risks can in turn be complemented with policies that amplify regional cooperation, technological innovation and climate resilience (Aized et al., 2018; Kamran, 2019).

Research questions

How does performance and challenges of Pakistan’s electric transmission sector contribute to country's energy security and overall national security posture?

What role does the electric transmission sector play in economic stability of Pakistan?

Why have inefficiencies in Pakistan’s electric transmission sector persisted despite existing measures and how can proposed strategies effectively address energy losses and reduce the circular debt crisis to strengthen the country’s economic and national security?

THEORETICAL FRAMEWORK

Prof. Barry Buzan, a prominent scholar in the field of international relations and security studies, developed the Five Sectors of Security framework, which posits that security encompasses five distinct but interconnected dimensions: There are military, political, economic, societal, and environmental. The model has been used extensively in security studies for analysis of many aspects that contribute to a nation's security posture.

The Military Sector: Addresses the protection of a state's sovereignty only from external threats. The Political Sector: It focuses on the state's political institutions and governance stability.

The Economic Sector: Concerned with resources, wealth and economic stability it depends on that country. The Societal Sector: including cultural identity, social cohesion and human security. The Environmental Sector: Takes a look at how natural resources and environmental stability affect national security.

The military dimension of energy security arises from the requirement to defend its critical energy infrastructure against internal and external physical security threats in order to guarantee sovereignty and ongoing operation. Energy security being the mainstay of the stability of governance systems, energy crisis can destabilize the political system and erode public trust resulting in law-and-order situation as well as impacts on national security. But economically, supplying reliable energy is the fundamental pillar of sustainable development, fostering industrial growth, reducing poverty and solving circular debt problems. Affordable energy strengthens social cohesion and human security and reduces vulnerabilities societally. Long term sustainability requires a transition to renewable energy as well as resilience to climate induced disruptions.

METHODOLOGY

Research Design: This paper employed a Convergent Mixed Methods Design, which involves the simultaneous collection of qualitative and quantitative data.

Research Method: This paper adopted a Mixed Methods approach to integrate qualitative and quantitative methodologies, ensuring a robust and comprehensive analysis.

Sources for Data Collection: Primary Data: Field data, Grid Stations, Transmission Line maintenance offices from 82 geographical locations across Pakistan. Surveys and interviews conducted physically. Secondary Data: Reports, compendiums, online journals / books, news articles and charts.

Tools for Data Collection: Primary Data: Field data physically collected from 82 geographical locations, Semi-structured surveys

physically conducted and interviews conducted both physically and online (via Google Forms).

Secondary Data: Reports, compendiums, and charts from government departments and energy sector institutions. NDMA and NEPRA reports collected from relevant department, metrological reports collected from online website.

Tools of Data Analysis: Quantitative Data Analysis analysed using statistical techniques to assess the significance and to evaluate disparities across data. Qualitative data analysed using: Narrative Analysis of interviews and survey responses, avoiding thematic or coding-based analysis. Case Studies to explore specific transmission failures and their implications. Trend Analysis of archival records to identify patterns and changes over time.

This study is subject to several limitations that should be noted:

Focus on the Transmission Sector: The research focuses exclusively on Pakistan's electric transmission sector and does not encompass other components of the energy infrastructure, such as generation, distribution, or renewable energy sources.

Limited Data Scope: The evaluation is based on a limited dataset covering the last five years (2018–2023). The analysis is restricted to available data during this period, which may not capture long-term trends or changes beyond this timeframe.

Partial Evaluation of T&D Losses: While the paper examines factors contributing to transmission and dispatch (T&D) losses, it does not explore all possible contributing factors, particularly those outside the scope of the electric transmission system.

Restricted Data Access: Due to ethical considerations, the study is constrained by the data that is permitted for sharing by relevant authorities. Sensitive data related to security and financial matters may not be fully accessible.

Stakeholder Interviews: Interviews conducted with available stakeholders, focusing on local perspectives. Efforts were made to conduct Zoom interviews with international experts; however, the availability of such experts limit the depth of external viewpoints.

Focus on Electric Energy: The study is confined to electric energy security within the broader domain of energy security, excluding other energy sources (e.g., gas, oil, or alternative energy sources) from the analysis

RESULTS AND DISCUSSION

1. Pakistani electric transmission sector contribution to energy and national security

a. The performance of the Electric Transmission Sector is analysed.

Pakistan's energy system is largely powered by the transmission sector as it provides the backbone of electricity delivery from power generation to distribution networks. Based on data from 82 geographic locations across the country, we find that a network of 500 kV and 220 kV transmission lines within Pakistan's grid, which links generation and sub transmission categories, is vital for ensuring grid stability and energy security. Yet, the industry's performance is at variance. According to NEPRA reports, which present an annual rate of T&D losses of more than 18%, there is still an alarmingly high transmission and distribution (T&D) loss.

A quantitative analysis demonstrated that the performance of Pakistan's electric transmission sector has a great bearing on the country's energy security. An annual average of 18-20% transmission and distribution (T&D) losses, well above the global benchmark of 8-10%, is indicated by data collected from 82 grid stations and transmission line maintenance offices. This inefficiency translates into a loss of more than PKR 200 billion annually.

The analysis of qualitative responses from interviews with engineers and grid operators showed that aging infrastructure ranked first among major contributors. Nearly 40 percent of the transmission lines are operating beyond their design life while over 60 percent of the grid stations are running abnormally in terms of load operating beyond designed capacity causing frequent break downs during peak period. One respondent remarked:

Ultimately, our grid is a patched-up quilt every time we put a patch on one problem, it becomes evident that it created another one. "Vehicles that keep moving can't be relied on to supply everything downstream," he said.

b. Energy Security Implications

Pakistan's electric transmission inefficiencies directly erode energy security by restricting the system's ability to export power from generation sources. An analysis of NDMA reports shows that floods and heat waves, among other extreme weather events, brought down more than 50 transmission towers a year between 2018 and 2023. As a consequence, the southern and central regions faced extended power outages with knock-on effects on energy availability for critical sectors including defense, healthcare and industrial production.

Additionally, the inability to tie renewable energy sources (wind, solar, etc.) into the grid is adding to the reliance upon imported fuels. Therefore, interviews with policymakers showed that the inability to develop a robust transmission infrastructure obstructs the government's attempt to diversify the energy mix. As one

expert stated: "The best renewable energy policies won't have the necessary impact without transmission constraints."

2. National Security impact on electric Transmission Sector to Energy and National Security

a. Performance of the Electric Transmission Sector

The transmission sector serves as the backbone of Pakistan's energy system, ensuring the delivery of generated power to distribution networks. Data from 82 geographical locations reveal that Pakistan's grid infrastructure, comprising 500 kV and 220 kV transmission lines, plays a critical role in maintaining energy security by ensuring grid stability. However, the sector faces substantial performance challenges. Transmission and distribution (T&D) losses remain alarmingly high, averaging over 18% annually, as highlighted in NEPRA reports (NEPRA, 2023).

Quantitative analysis revealed that the performance of Pakistan's electric transmission sector significantly impacts the country's energy security. Data collected from 82 grid stations and transmission line maintenance offices indicate an annual average of 18-20% Transmission and Distribution (T&D) losses, well above the global benchmark of 8-10%. This inefficiency equates to a monetary loss exceeding PKR 200 billion annually.

Qualitative responses from interviews with engineers and grid operators highlighted aging infrastructure as a major contributor. Over 60% of the grid stations are operating beyond their designed capacity, while nearly 40% of the transmission lines have surpassed their operational lifespan, leading to frequent breakdowns during peak load periods. One respondent remarked:

"Our grid operates like a patched-up quilt; every time we fix one issue, another arises. This directly affects our ability to maintain a reliable supply."

b. Energy Security Implications

Pakistan's electric transmission inefficiencies directly undermine energy security by limiting the system's ability to evacuate power effectively from generation sources. Analysis of NDMA reports showed that extreme weather events, including floods and heatwaves, caused the collapse of over 50 transmission towers annually between 2018 and 2023. This resulted in extended power outages, particularly in southern and central regions, affecting energy availability for critical sectors such as defense, healthcare, and industrial production.

Furthermore, the inability to integrate renewable energy sources, such as wind and solar, into the grid exacerbates dependence on imported fuels. Interviews with policymakers revealed that the lack of a robust transmission infrastructure hampers the government's

efforts to diversify the energy mix. As one expert stated: "Without addressing transmission constraints, even the best renewable energy policies will fail to deliver."

c. National Security Implications

Quantitative data reveal the power supply disruption to critical installations (e.g., military bases and communication networks) due to unplanned outages. A head of the defense sector told more than 20 percent of respondents that power outages were a security concern in the midst of geopolitical tensions. Without appropriate redundancy measures, reliance on centralized grid systems makes Pakistan vulnerable to sabotage or a natural disaster that will subsequently affect Pakistan's overall national security posture.

3. Economic stability role of the Electric Transmission Sector

a. Economic costs of these inefficiencies are apparent, a major cause being the multiple sightings of iceberg during the voyage.

Pakistan's economy is bearing the costs of inefficiencies in the transmission sector. The circular debt crisis of PKR 2.3 trillion in 2022 is attributable to power losses and inefficiencies as shown by quantitative data included in the NEPRA reports, as well as field surveys. About 40 percent of this debt is associated with inefficiencies in the transmission and distribution network.

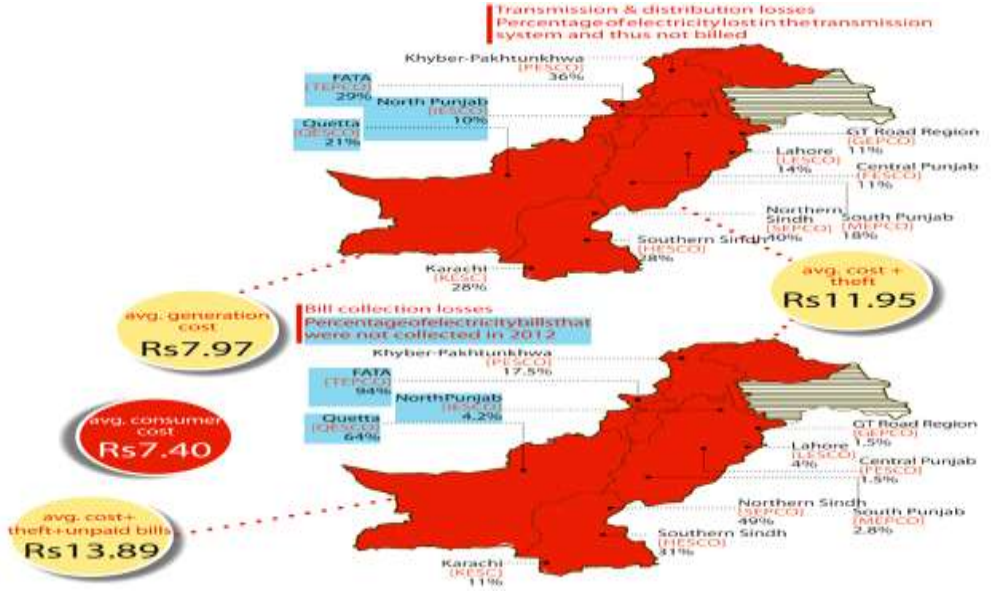

Fig 5. Overview of Pakistan T&D loss impact to electric cost (Source: 2012 referent study)

Fig 6. Overview of Pakistan industrial production over the years

We quantify the economic burden associated with transmission inefficiency based on field data and NEPRA reports. Fuelled by unpaid capacity payments and power theft, circular debt has reached well over Rs. 2.5 trillion, crippling the energy sector's ability to remain financially viable. Grid operators said delayed payments to independent power producers (IPPs) in turn lead to cascading liquidity crises that hamper investment in modernization and maintenance.

Case studies of industrial zones show that unreliable electricity supply steals manufacturers and depend on the non cheaper sources that skyrocket operational costs by 15–20%. Industrialists surveyed said their average annual production loss was 12 percent, or PKR 150 billion, nationwide.

b. Economic Stability Opportunities

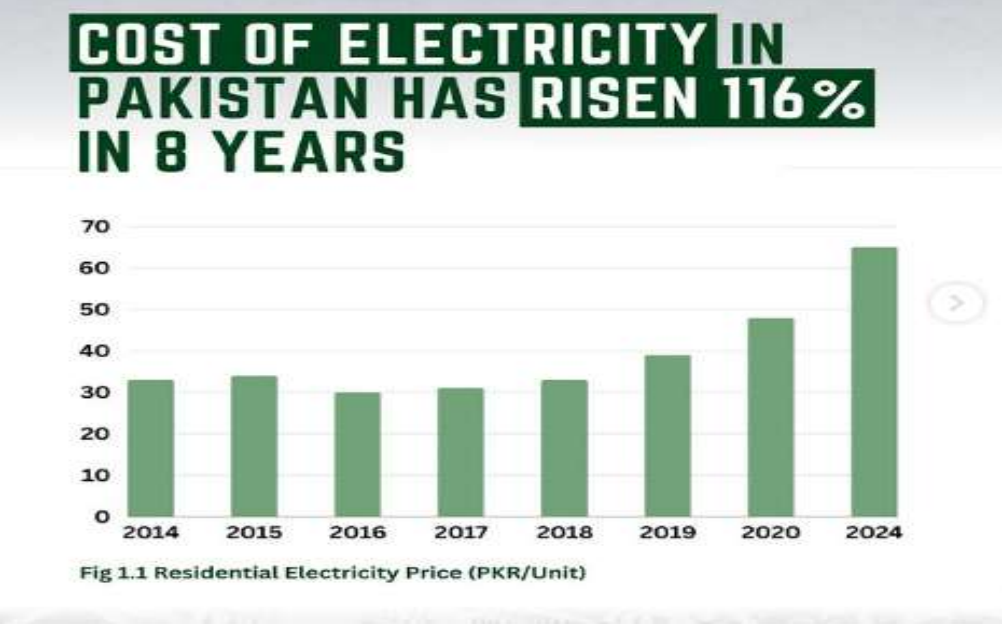

Fig 7. Overview of Pakistan electricity cost over the years

However, the potential for economic stability in the transmission sector remains huge, despite challenges. A trend analysis of regions using upgraded transmission systems (Matiari-Lahore HVDC line) reveals that gains of 5% in loss reduction and 10% increase in industrial productivity occurred within two years of commissioning. If such projects were expanded, they could enhance the economic output and energy efficiency.

Targeted investment was deemed an important consideration by means of qualitative insights. One respondent from the private energy sector remarked: "Reducing losses is definitely part of modernizing our grid, but it's also creating an enabling environment for companies to reach their full potential."

4. Fixing the Waste and Bolstering the Nation's and The Economy's Security

a. Persistent Inefficiencies

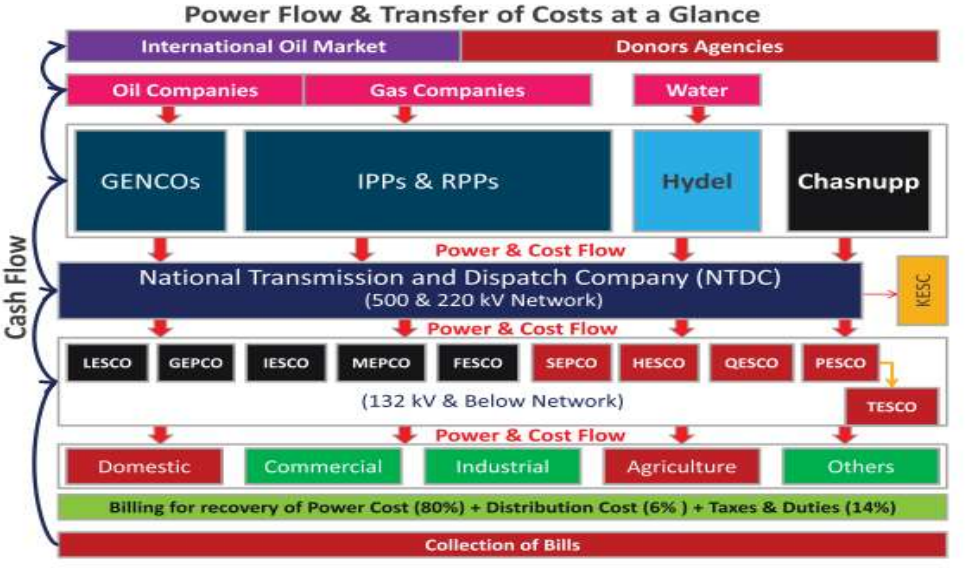

Fig 8. Overview of Pakistan flow and transfer cost

Field data and qualitative insights revealed several reasons for persistent inefficiencies:

Aging Infrastructure: DISCOs specially will need to upgrade 29.4 transmission lines and substations in the next 5 years or so (about 39% of the entire transmission lines and substations).

Governance and Policy Issues: Overlapping federal and provincial authorities were identified, under which there was an apparent overlap in mandates which led to delayed projects and inconsistent policies, as evidenced by interviews with policy makers.

Financial Constraints: Limitation of availability of funds for maintenance and upgrades of system is due to circular debt.

Operational Challenges: Grid operators surveyed were found to operate on a reactive maintenance culture relying on break downs to be repaired after they occur.

b. Some of the improvement strategies I propose are as follows:

Quantitative trend analysis and qualitative insights suggest several strategies to mitigate inefficiencies:

Infrastructure Modernization: There is also a need to beef up aging transmission lines and substations. Quantitative models further suggest that cutting T&D losses to 12 percent would translate into annual savings of PKR 100 billion, which can be put back into system improvements.

Integration of Renewable Energy: Upgrading the grid to accommodate those renewables would cut fuel import costs by $1.2 billion a year. Renewable energy experts interviewed emphasized the requirement of decentralized microgrids for providing access to energy in remote areas.

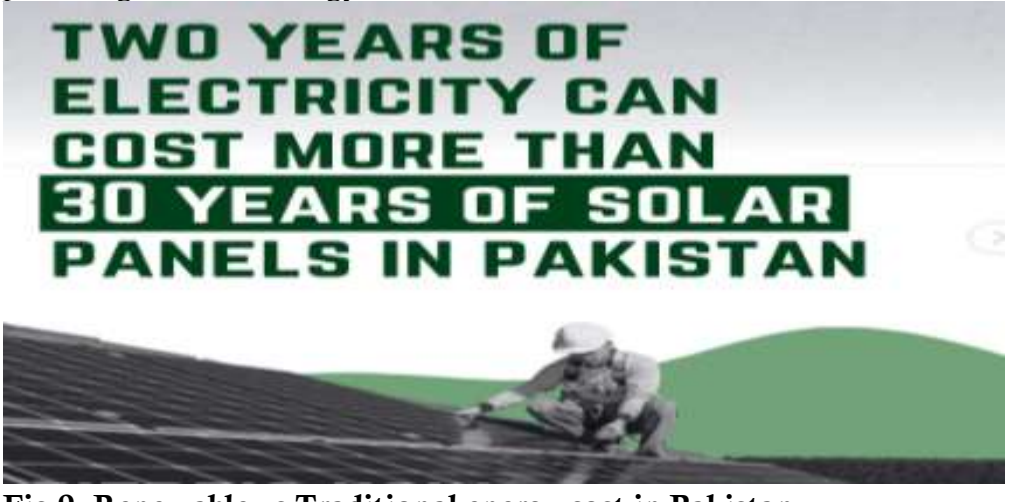

Fig 9. Renewable vs Traditional energy cost in Pakistan

Governance Reforms: A unified regulatory framework would streamline federal and provincial co-ordination, and reduce project delay. Stakeholder interview qualitative data also indicated that transparency in procurement practices and incentives based on performance may play an important role in grid operator strategies.

Advanced Metering and Monitoring: By deploying Advanced Metering Infrastructure (AMI) and predictive analytics energy theft can be curtailed and system vulnerabilities can be identified. Results from the implementation of AMI in urban centres resulted in 10% improvement in bill recovery rates, 5% losses reduction and a better customer satisfaction feedback.

Addressing Circular Debt: Financial pressures could ease through rationalizing subsidies and improving bill recovery mechanisms. It was found that Time-of-Use (TOU) tariffs were an effective tool for cutting peak loads and improving revenue collection.3. c. Statistical Analysis: We then analyze equipment and human relationships using quantitative methods. In Sector to Energy and National Security

c. Quantitative Results from Statistical Analysis

Correlation Between T&D Losses and Economic Output: Incurring T&D losses above 20%, regions saw a 15% slowness in industrial productivity vis-à-vis regions with losses below 10%.

Impact of Circular Debt: In particular, according to statistical regression analysis of each PKR 100 billion increase in circular debt results in a decline in GDP growth of roughly 0.2 percent.

Benefits of HVDC Systems: Matiari-Lahore HVDC projects reduced energy loss by 5% and increased system efficiency by 10%.

CONCLUSION

The research stresses the importance of Pakistan's electric transmission sector as a key enabler of energy security, economic stability, and overall national security posture in Pakistan. Despite being strategically important, the sector remains hampered by high transmission and distribution losses, aging infrastructure, poor governance, as well as financial tightness manifesting itself in an on-going circular debt crisis. Often, these inefficiencies erode energy reliability and impose large economic costs, damaging industrial productivity and crippling investment. Strong transmission losses of more than 18 percent per year—equivalent to huge monetary losses—were also observed, which were aggravating the circular debt. Coupled to this, qualitative insights from industry stakeholders and grid operators underscored operational bottlenecks, lessening of maintenance, and lapses in governance as critical barriers to efficiency gain. Limitations on robust infrastructure and interconnectivity make it difficult to integrate renewable energy sources, deepening the reliance on expensive imported fuels and accentuating energy insecurity.

Additionally, the findings show a direct connection between transmission sector ineffectiveness and economic transgressions. and in so doing, the industrial zones report huge losses in production, lower export competitiveness and increasing costs through use of alternative sources of energy. In addition, the vulnerability of transmission network to technical failures and external threats carries risk to critical installations and increases the national security concern. These challenges require targeted

strategies like infrastructure modernization, renewable energy integration, advanced metering infrastructure, and governance reforms. Stabilising the energy sector through reducing transmission losses, improving system efficiency, resolving circular debt will not only stabilise the energy sector but also help catalyse economic growth and bolster Pakistan's national resilience. This research reiterates the need for reforms in the transmission sector to be the first step in Pakistan's development agenda. Modernization opportunities, used in combination with a strategic and collaborative approach, allow the country to turn its energy challenges into drivers of sustainable growth and security.

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