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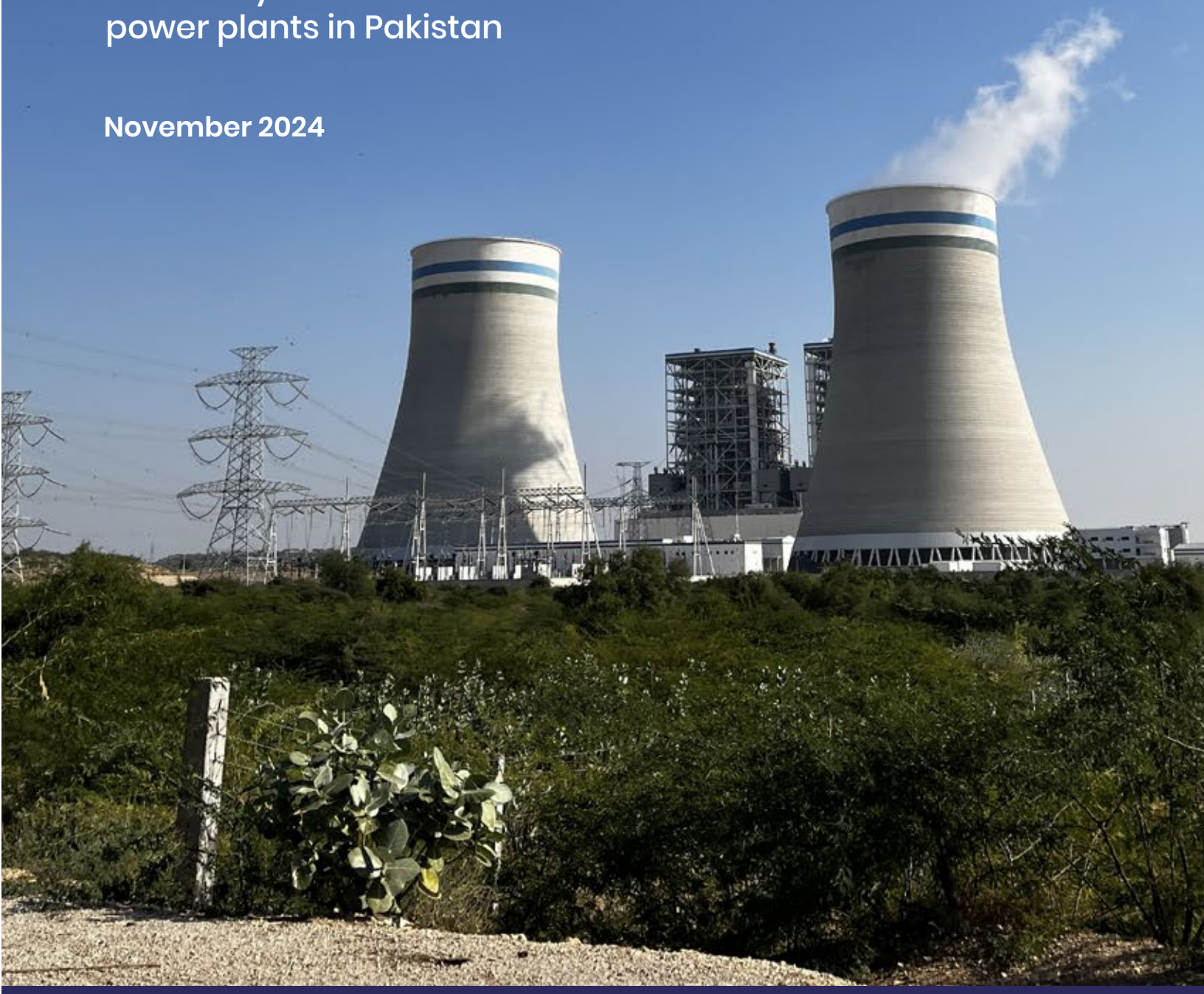
Transitioning Away From Coal:

An orderly retirement of coal power plants in Pakistan

November 2024



Authors: Zainab Babar, Dr. Khalid Waleed

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Mailing Address: PO Box 2342, Islamabad, Pakistan.
Telephone: +92 (51) 2278134, 2278136, 2277146, 2270674-76
Fax: +92 (51) 2278135

www.sdpi.org

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Abbreviations

ADB	Asian Development Bank
BAU	Business As Usual
BIO	Board of Investment
BRI	Belt and Road Initiative
BRIGC	Belt and Road Initiative Green Coalition
CCCI	Coal to Clean Credit Initiative
CFPP	Coal-Fired Power Plant
COD	Commercial Operation Date
COP26	26th Conference of the Parties (UNFCCC)
CPEC	China-Pakistan Economic Corridor
CPHGC	China Power Hub Generation Company
CSOs	Civil Society Organizations
DEA	Data Envelopment Analysis
DMUs	Decision-Making Units
DISCOs	Power Distribution Companies
DFI	Development Finance Institutions
EJ	Exajoule
ETM	Energy Transition Mechanism
EPA	Environmental Protection Agency
G7	Group of Seven (major advanced economies)
HRCP	Human Rights Commission of Pakistan
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IPCC	Intergovernmental Panel on Climate Change

IPPs	Independent Power Producers
IUCN	International Union for Conservation of Nature
IMF	International Monetary Fund
JETP	Just Energy Transition Partnership
KWh	Kilowatt-hour
LPGCL	Lakhra Power Generation Company Limited
MEE	Ministry of Ecology and Environment of the People's Republic of China
MOFCOM	Ministry of Commerce of the People's Republic of China
MOPD&SI	Ministry of Planning, Development, and Special Initiatives, Pakistan
MW	Megawatt
NEPRA	National Electric Power Regulatory Authority
NPPMCL	National Power Parks Management Company Limited
PCRET	Pakistan Council of Renewable Energy Technologies
PFAN	Private Financing Advisory Network
PPIB	Private Power and Infrastructure Board
PPAs	Power Purchase Agreements
PPCA	Powering Past Coal Alliance
PPP	Public-Private Partnership
RE	Renewable Energy
RLNG	Re-gasified Liquefied Natural Gas
RFO	Residual Fuel Oil
R&D	Research and Development
SEPA	Sindh Environmental Protection Agency
TEL	Thar Energy Limited
TWh	Terawatt-hour
UNFCCC	United Nations Framework Convention on Climate Change
WAPDA	Water and Power Development Authority
WWF	World Wide Fund for Nature

Executive Summary

Coal-fired power plants (CFPPs) account for a significant portion of global CO_2 emissions, with around 66% emanating from coal-based electricity generation. To meet the Paris Agreement goals, developed and developing nations are urged to phase out unabated coal. In 2023, the United Nations Climate Change Conference (COP 28) marked a pivotal moment by signalling the end of the fossil fuel era and laying the groundwork for an orderly transition.

Globally, efforts are concentrated on restraining global warming to 2°C or below, envisioning the elimination of coal usage by 2050. However, this necessitates retirement of young coal fleets in many developing countries which raises the concerns of stranded assets. For countries like Pakistan, the challenges in transitioning away from coal are multi-pronged. In Pakistan, the key challenge is the long-term Power Purchase Agreements (PPAs) signed with the Chinese State Enterprises. Secondly, Pakistan's coal fleet is relatively young, average age of CFPPs in Pakistan is 6-7 years. However, it is important to mention here that the utilization rate of these CFPPs is low, and these plants are generating excess capacity thereby contributing to inefficiencies in the power system.

In FY 2024-25, 18.9 percent of total capacity payments or Rs 395.402 billion will be paid to CFPPs. The share of capacity charges allocated to each CFPP reveals that the Engro Thar Power receives approximately 30%, Sahiwal Imported Coal accounts for 25%, while both China Hub Power and Port Qasim each represent about 13% of the total payments. Their utilization rates are notably low with Sahiwal imported coal and Port Qasim stands at lowest rate of 51% and 27% respectively.

The economically viable and strategically suitable case for Pakistan is to retire the inefficient coal power generation to improve country's Global positioning, to make industry Globally compatible and to provide the opportunity to yield substantial financial returns by earning carbon credits through avoided emissions. To facilitate the phasing down of CFPPs in emerging economies, the Asian Development Bank initiated the Energy Transition Mechanism (ETM), which accelerates coal phase-outs through regional and international collaborations. Besides this, several initiatives that include Just Energy Transition Partnerships (JETPs), Coal to Clean Credit initiative (CCCI) are there to facilitate a smooth transition from to clean energy sources by providing financial and technical assistance.

The economic case for the early retirement of coal-fired power plants in Pakistan is compelling. As mentioned above, those plants whose utilization rates are low and capacity charges are high are financial strain on nation exchequer. Generous allowances such as dollar-indexation, fixed-capacity charges, long-term power purchase contracts and sovereign guarantees for payments often insulate these plants from market forces and make them inefficient and less competitive.

Considering these facts, the ongoing situation necessitates an orderly phase-down of CFPPs for Pakistan's economic stability.

Given the context of ADB's pre-feasibility report for early coal retirement in Pakistan, this study develops a shadow retirement plan for early coal phase out, the study map-out the factors influencing the transition away from coal to renewable energy. Enabling factors include global commitments such as the Paris Agreement, government policies promoting renewable energy, growing public awareness, abundant renewable resources, technological advancements, provincial initiatives, international collaborations, declining costs of renewable energy technologies, and innovative financing mechanisms. These factors provide a foundation for accelerating the adoption of renewable energy and driving the transition away from coal.

In Pakistan, there are multiple barriers in transitioning from coal to renewables such as infrastructure limitations, political interests tied to the coal industry, financial constraints, policy uncertainty, lack of public awareness and education, inadequate technology transfer, insufficient regulatory frameworks, and limitations on integration of renewable energy into existing grids pose significant challenges.

To navigate the transition effectively, a strategic plan is needed for orderly retirement of CFPPs. In this context, this study proposes a strategy for orderly retirement of CFPPs in Pakistan based on the Data Envelope Analysis (DEA). This analysis utilizes various parameters including energy generation by CFPPs, varying capacity payments per unit, emissions from CFPPs, the utilization rates, and the varying financial profiles involving debt and equity. Based on the analysis, the Sahiwal imported coal and China power hub are identified as priorities for early retirement. Strategic decisions based on the analysis can promote sustainability and mitigate the impacts of coal-fired power generation in Pakistan.

The government is recommended to collaborate with Chinese coal-fired power plant owners and relevant stakeholders to devise a medium to long-term strategy for the orderly retirement of coal-fired power plants. Establishing Just Energy Transition Partnerships (JETPs) can facilitate transitioning away from coal and incentivizing the adoption of renewable energy. Restructuring Power Purchase Agreements (PPAs) to encourage the transition to renewables and exploring financing mechanisms for repurposing are recommended.

Moreover, implementing a carbon pricing mechanism and leveraging initiatives like the Coal to Clean Credit Initiative (CCCI) and the Energy Transition Mechanism by the Asian Development Bank can facilitate the phasedown of CFPPs. Collaboration through platforms involving stakeholders for regional and international cooperation, and public-private partnerships can accelerate the adoption of best practices and achievement of transition goals.

Additionally, developing a capacity building program in collaboration with research institutions and industry associations, and fostering partnerships with leading Chinese entities in renewable technology, can expedite capacity development and support the transition to renewable energy sources.

01
Introduction

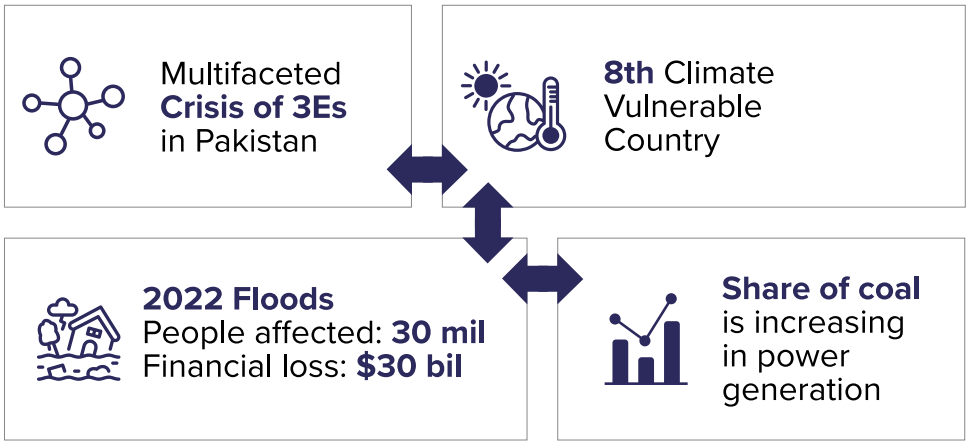
The 21st century has witnessed a worsening of global climatic conditions, from the growing greenhouse gases to catastrophic floods, heat waves and droughts. To combat the catastrophic impacts of climate change, to stabilize the atmospheric concentration of CO2 and to avoid the serious and disastrous impacts of climate change, global emissions must be reduced by roughly 80% from business as usual (BAU) levels over the next several decades (Brutschin, et. al, 2022). The Paris Agreement, enacted in 2015, established specific actions and targets for reducing greenhouse gas emissions for mitigation and adoption of climate change. Coal fired power plants (CFPPs) contributes around 44% of the total 33 giga-tonnes (Gt) of CO2 of global energy related CO2 emissions, 66 % of these emissions came from coal use for electricity generation (He et al,2020). There is clear agreement in climate science that to increase the probability of reaching the goals of the Paris Agreement, the use of unabated coal in the power sector needs to decline rapidly (Cui et al., 2019; Spencer et al., 2018; Tong et al., 2019). In 2023, the United Nations Climate Change Conference (COP 28) made an agreement that signals the "beginning of the end" of the fossil fuel era by paving the path for an orderly, just and equitable transition, underpinned by deep emissions cut and scaled-up finance.

Globally, all political and governance strategies are aimed at constraining global warming to 2 or below and envisions elimination of coal usage by the year 2050 (Intergovernmental Panel on Climate Change, 2022). This implies an early retirement of coal fleets in many developing countries, which have witnessed a substantial increase in coal capacity over the past two decades (Tong et al., 2019). The early retirement of power plants before reaching their usual operating lifetime of 40-60 years; this places the burden of stranded assets disproportionately on those developing countries (Edwards et al., 2022). For developing countries like Pakistan, phasing down the unabated coal fired power plants to meet the climate agreements is a daunting challenge. In this regard, to facilitate the developing countries in phasing out CFPPs, the Asian Development Bank initiated the Energy Transition Mechanism (ETM) which accelerates the phasing out of CFPPs through regional and international partnerships. The ETM provides financial capital to accelerate the retirement or repurposing of coal power plants; this mechanism started off with three countries i.e. Indonesia, the Philippines, and Vietnam, and now has extended to Pakistan and Kazakhstan as pre-feasibility of early retirement of CFPPs.

In Pakistan, the coal consumption in the power sector increased significantly over the past decade; it's share went from 2.3% in 2015 to 64.7 % in 2023 (Energy Yearbook, 2023) power system statistics. Most of the coal related built-up in the recent years is under the China Pakistan Economic Corridor (CPEC); though these power plants

have contributed positively to Pakistan's energy security by developing its much-needed power generation capacity which fell below its peak demand in 2008 to 2015. Now, the time demands transitioning away from coal because of the rising environmental vulnerabilities. The escalating severity of disastrous impacts of climate change in Pakistan can be visualized through the recent devastating floods in 2022, which affected over 33 million people (Miranda et al., 2023). Changing seasonal weather patterns, rising temperatures, variability of monsoons, and melting of northern glaciers; further compounded by recurring extreme weather events and natural disasters are the result of climate change. The 3Es of energy, economy and environment are linked strongly with the climate change thereby resulting in multifaceted crisis.

Figure 1: *Climate Change Impact and Coal power generation in Pakistan*



1.1. The Environmental impact of Coal

Coal serves as a primary source of pollution in Pakistan, significantly contributing to air and water pollution as well as adverse health effects. The combustion of coal in power plants and industrial facilities releases a plethora of pollutants, having deadly impact on human wellbeing and the surroundings, leading to lungs damage, heart diseases, and worsening issues like smog and acid rain (Rehman et al., 2018; Javaid et al., 2019). Additionally, coal mining activities contribute to soil erosion, deforestation, and habitat destruction, further intensify environmental degradation (Khan et al., 2020; Mahmood et al., 2024).

Despite efforts to enhance coal-fired power plant efficiency and implement emission control technologies, the environmental footprint of coal remains significant in Pakistan due to availability and reach. Therefore, transitioning towards cleaner energy sources and implementing rigorous pollution control measures are vital to mitigate the adverse impacts of coal use and ensure an improved and more sustainable future for the country like Pakistan.

Moreover, the imperative to curtail global carbon emissions, and address domestic environmental concerns aligns with the global climate commitments, Pakistan needs to shift away from coal, but this shift requires a systematic approach for early retirement of coal power plants. This shift, if not, done in orderly, just and equitable manner can gravely complicate the matters of energy security, unemployment, and stranded assets (Spencer et al., 2018). In this regard, the study's focus is on devising a strategy for orderly retirement of coal power plants, based on empirical analysis of coal fired power plants in Pakistan.

02

The evolving dynamics of energy landscape and coal consumption trends in Pakistan

The energy landscape of Pakistan has undergone significant transformations driven by the need to meet growing energy demand, reduce dependence on costly imports and to support economic development.

Coal Consumption Trends in Pakistan

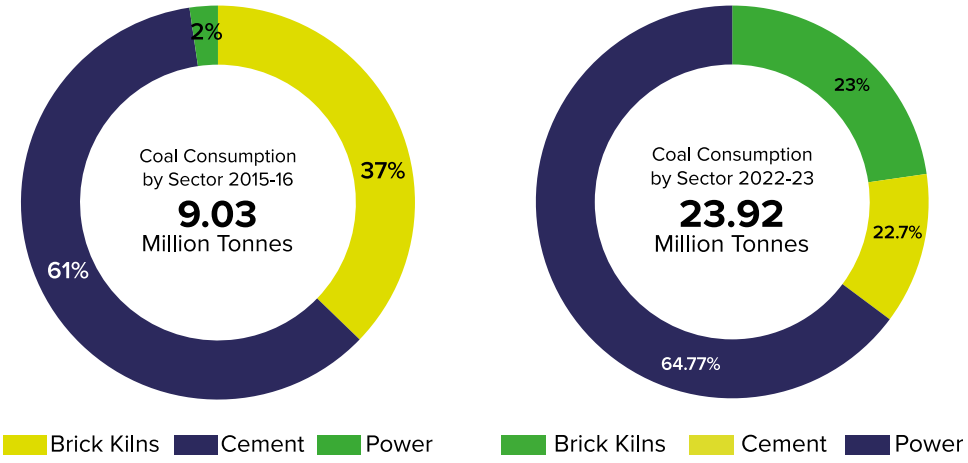
Coal is Pakistan's most prevalent and third-largest energy source, contributing 15.2% to the overall energy consumption (Pakistan Energy Yearbook- 2023). Pakistan's coal consumption was 0.62 EJ, ranking twelfth among Asia-Pacific countries (Tang et al., 2024). This is because Pakistan has the world's seventh-largest coal reserves, with about 9000 Btu/lb of heating value and 185.175 billion tons of reserves. In 2015, total coal consumption in Pakistan was 9.03 million tonnes, which increased exponentially in the next few years and reached 23.92 million tonnes in 2023 (Energy Year Book 2023). In this period, a significant increase in coal consumption was observed in the power sector, shown in figure 1 below.

2.1. Historical Development of Coal fired Power Plants in Pakistan

Pakistan's energy landscape has undergone significant transformations driven by the imperative to meet escalating energy demand, to reduce reliance on costly imports and to stimulate economic growth. This transition resulted in heavy dependence on coal as a cost-effective energy source without considering the environmental impact of coal consumption. Most of coal fired power plants are owned by the Chinese and operate as an Independent Power Producer (IPPs). This section discusses the historical development of coal fired power plants in Pakistan.

Coal Consumption trends from 2015 -2023 **Figure 2**

Data Source: Pakistan Energy Yearbook 2023



The Lakhra Power Plant

The first government owned coal-fired power plant in Pakistan, the Lakhra Power Plant, became operational in 1995. Situated in the Jamshoro District of Sindh, adjacent to the Indus River's right bank near Khanot, this plant is under the ownership and operation of the Lakhra Power Generation Company Limited (LPGCL). Notably, it distinguishes itself as the sole coal-fired power plant in Pakistan utilizing locally sourced coal from the nearby Lakhra Coal Mines, located approximately 25 kilometers away. Comprising three units, each boasting a capacity of 50 MW, the Lakhra Power Plant collectively yields a total capacity of 150 MW. In 2023, the Cabinet Committee on Energy (CCoE) retired the Lakhra power plant due to high production cost and low efficiency.

Sahiwal Imported Coal Power Project

The construction of the Sahiwal Imported Coal Power Project began in May 2017 and was completed in a record time of fewer than three years. Wang Yang, the Vice Premier of China, visited Pakistan in August 2015 and attended the groundbreaking ceremony of the Sahiwal project. His visit underscored the importance of the project in strengthening bilateral ties between China and Pakistan. MOU was signed between China Huaneng Group and the Punjab government. This MOU, signed in April 2015, laid the foundation for cooperation in the development of the Sahiwal Imported Coal Power Project. The Sahiwal Imported Coal Power Project became operational in June 2017, marking a significant milestone in Pakistan's efforts to enhance its power generation capacity and address energy shortages. Its total installed capacity is 1320 MW.

Port Qasim Coal Power Plant

The Port Qasim Coal Power Plant is situated near the Port Qasim Authority in Karachi, Sindh province, Pakistan. Karachi is the largest city and economic hub of Pakistan, and Port Qasim serves as one of the country's major ports, making it an ideal location for the power plant to facilitate efficient coal imports and power distribution. The construction of the Port Qasim Coal Power Plant commenced in early 2015 and was completed in phases. The first unit became operational in 2017, and subsequent units were commissioned in the following years. Vice Premier of China, Wang Yang's visit to Pakistan in 2015 also included discussions and agreements related to the Port Qasim Coal Power Plant, further solidifying China-Pakistan cooperation in the energy sector. MOU between Power Construction Corporation of China (Power China) and the Government of Pakistan was signed. This MOU outlined the terms of cooperation for the development and construction of the Port Qasim Coal Power Plant. NPPMCL, a subsidiary of the Ministry of Energy (Power Division) of Pakistan, collaborated with Power China in the development and operation of the Port Qasim project. The total installed capacity of Port Qasim coal power plant is 1320 MW.

Engro Thar Coal

The construction of the Engro Powergen Thar Block II project began in 2016 and was completed in phases. The power plant became operational in 2019. An MoU was signed to outline the collaboration between Engro Powergen Thar Limited and SECMC for the development of the Thar Block II coal project. The Engro Powergen Thar Block II project began its commercial operation in 2019. The Engro Powergen Thar Block II project is in the Tharparkar district of Sindh province, Pakistan. Thar parkar is known for its vast coal reserves, and the development of the Thar coalfield has been a key focus for the government to harness indigenous energy resources for power generation. The total installed capacity of Engro Thar Coal is 660MW.

China Hubco Coal

The construction of the China Power Hub project began in 2017, and it was completed in phases. An MoU was signed to outline the collaboration between China Power Hub Generation Company (CPHGC) and HUBCO for the development of the China Power Hub project. It established the framework for cooperation in power generation activities in Hub, Balochistan. CPHGC collaborated with China Power International Holding limited (CPIH), a subsidiary of China Power Investment Corporation, for the development and financing of the China Power Hub project. The China Power Hub project began its commercial operation in subsequent years after the completion of construction in 2019. It contributes to Pakistan's power generation capacity, particularly in the Hub region of Balochistan. The China Power Hub project is located near Hub, a city in the Lasbela District of Balochistan province, Pakistan. Hub is strategically located near the Arabian Sea coast and serves as an important industrial and economic hub in the region. The total installed capacity of China hubco coal is 1320 MW.

Lucky Coal

Lucky Electric Power Company, a wholly owned subsidiary of Lucky Cement Limited, is actively engaged in the development of a 660 MW coal-fired power plant featuring ultra-supercritical technology. Situated in Deh Ghangiaro, Bin Qasim, Karachi, this project represents a significant stride towards enhancing power generation capabilities in the region. Marking a significant milestone, the company achieved its Commercial Operation Date (COD) on March 21, 2022, thereby solidifying its contribution to the national grid. With seamless integration, the plant now plays a crucial role in meeting the energy needs of the nation.

Thar Energy Limited (TEL)

Initially Thar Energy Limited (TEL) was part of Thar Block II, later it became a separate endeavour. The project faced delays but progressed with financing from Chinese and Pakistani banks. In October 2022, the plant was inaugurated. The total installed capacity of TEL is 330 MW.

Thar Coal Block-I

The construction of the Thar Coal Block-I project began in 2019 and was completed in phases. The project became operational in subsequent years fully operational in 2023. It represents a significant milestone in Pakistan's efforts to utilize its indigenous coal reserves for power generation and reduce reliance on imported fuel sources. The Thar Coal Block-I project is in Mithi Tharparkar district of Sindh province, Pakistan. Tharparkar is known for its vast coal reserves, and the development of the Thar coalfield has been a key focus for the government to harness indigenous energy resources for power generation. Its total installed capacity is 1320 MW.

Thal Nova - Thar Block Ii

ThalNova, a 330MW lignite-fired power plant in Thar Coal Block II, Sindh, is a crucial component of the CPEC. It's a joint venture involving Hub Power Company Limited (HUBCO), Thal Limited, Novatex Limited, China Machinery Engineering Corporation (CMEC), and Descon Engineering Limited, with HUBCO holding 38.3% shares and management control. Utilizing European technology from General Electric for its Boiler, Turbine, and Generator, ThalNova boasts high reliability and emission controls surpassing SEPA limits, promising electricity at competitive rates. With financing from Chinese and local syndicates, construction began in March 2019, ensuring timely completion for commercial operations by March 2025, contributing to local employment in Thar and nearby communities.

03

Current scenario of coal fired power plants and coal mining in Pakistan

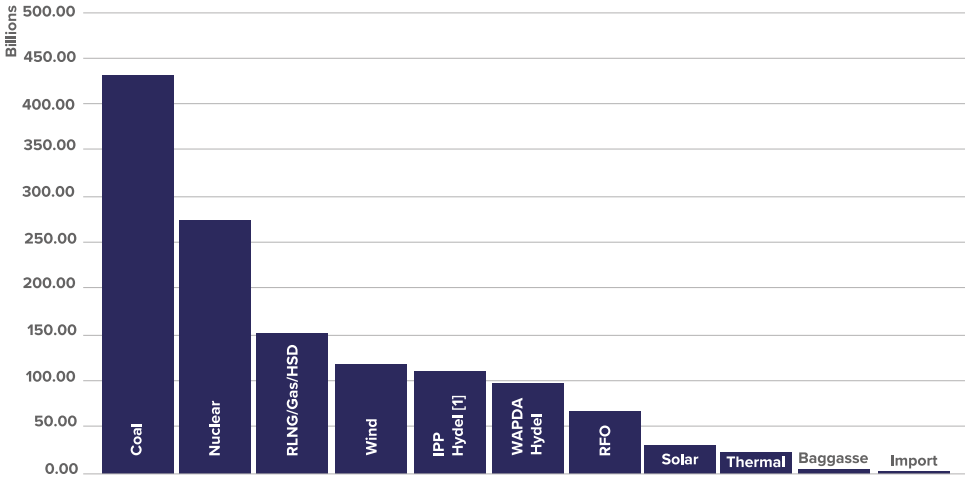
The installed capacity for imported coal-based power projects stands at 3960 MW, while coal contributes 2640 MW from Block I and Block II of Thar coal mines. More than 60% of the installed capacity operates on imported coal. However, the imported coal operates without regulations in terms of price determination. Power plants have engaged in long-term contracts for coal procurement from South Africa and Indonesia, adhering to industry standards. However, there has been a substantial increase in price for imported coal.

Currently, the government has permitted coal imports from Afghanistan due to the ongoing global commodity super-cycle influenced by factors such as the Russia-Ukraine conflict and post-pandemic logistics disruptions, and to mitigate the impact of escalating imported coal prices and lessen pressure on foreign exchange reserves. It is worth mentioning that coal from Afghanistan is also priced in US$ per ton. The National Electric Power Regulatory Authority (NEPRA) has issued binding guidelines on power plants importing coal from Afghanistan. While progress has been made in conducting trials using coal from Afghanistan's spot market, challenges remain due to insufficient market capacity and a lack of established pricing indices. The authority has recently introduced guidelines for spot procurement of coal.

The Issue of Capacity Charges

Increasing generation capacity to meet peak demand is vital but it comes with a cost. Pakistan experienced a significant increase in capacity payments from Rs 1082 billion to Rs 2512 billion due to the depreciation of the Pakistani rupee against the US dollar. The escalating capacity payments are primarily driven by the Independent Power Producers (IPPs). In 2023, a 60% increase in capacity payments was reported from locally funded RLNG plants and a staggering 145% increase from foreign funded coal plants. The capacity payment for foreign-funded projects stood at Rs 3,218 per kW per month when the exchange rate was Rs100/$, while locally funded projects incurred a payment of Rs 1,436 per kW per month. However, with the exchange rate now at Rs 300/$, the capacity payment has surged to Rs 7,097 per kW per month for foreign-funded projects and Rs 1,857 per kW per month for locally funded projects. In terms of the total de-rated available capacity in the system, excluding K-Electric, it amounts to 36,277 MW, with foreign-funded projects contributing 21,374 MW and locally funded projects contributing 14,903 MW (Business recorder, Sep 2023). The breakdown of capacity payments across various sources is as follows: Coal – 431,781 million, nuclear 273,953 million, RLNG/Gas. HSD – 152,358 million, wind – 119,529 million, IPP hydel – 110,872 million, WAPDA hydel – 100,219 million, RFO – 69,226 million, solar – 31,349 million, thermal – 24,932 million, Baggasse – 5,215 million, import – 1,400 million (State of Industry Report, 2023).

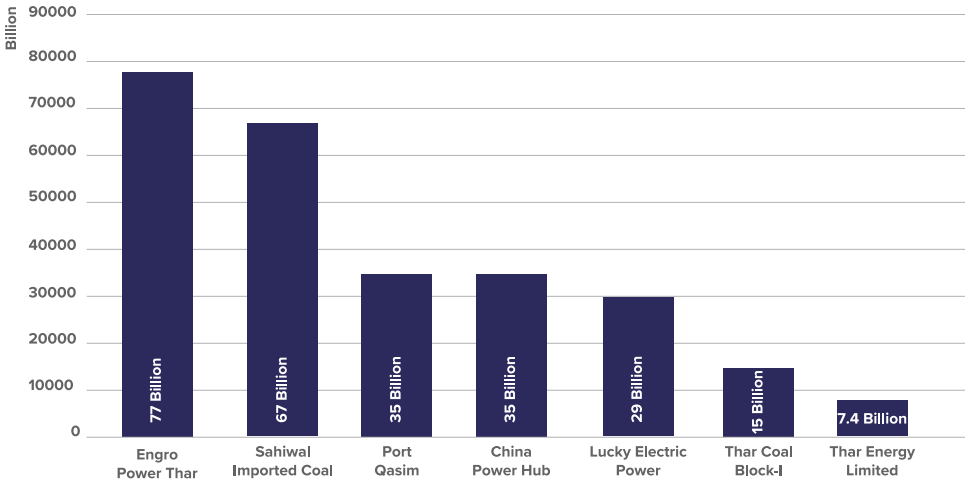
Capacity Charges (Billion Rs) of CFPPs **Figure 3:**



Capacity Payments by CFPPs

One of the major challenges of the energy sector in Pakistan is the increasing capacity payments and over-reliance on imported fuels. Coal-fired power plants in Pakistan receive capacity payments as part of the country's energy market structure. These payments are made to ensure that coal-fired plants maintain sufficient capacity to meet electricity demand. The capacity payments serve as incentives for power generators to invest in and maintain their facilities, helping to ensure grid stability and reliability. The capacity payments made to the coal power plants in 2023 are shown below:

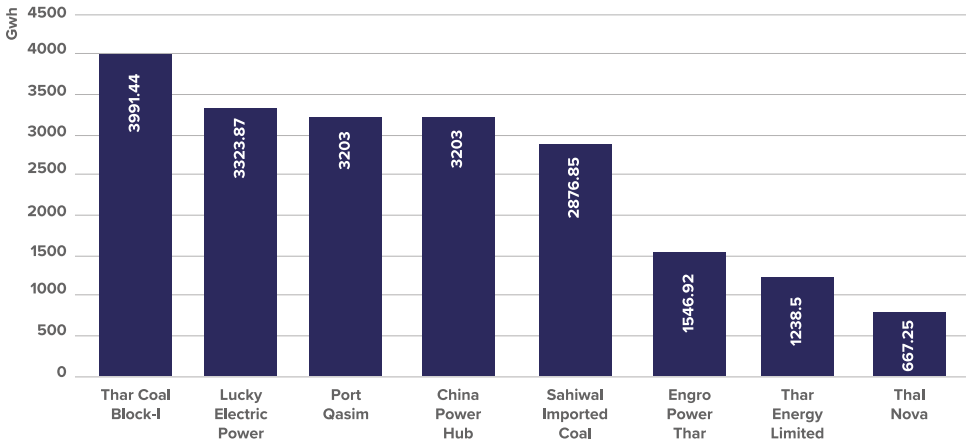
Capacity Charges (Billion Rs) of CFPPs **Figure 4**



Energy Generated by CFPPs

The following graph shows the amount of energy generated by each coal fired power plant. On average, these power plants produce several hundred megawatts to over a thousand megawatts of electricity depending on their capacity and operational efficiency.

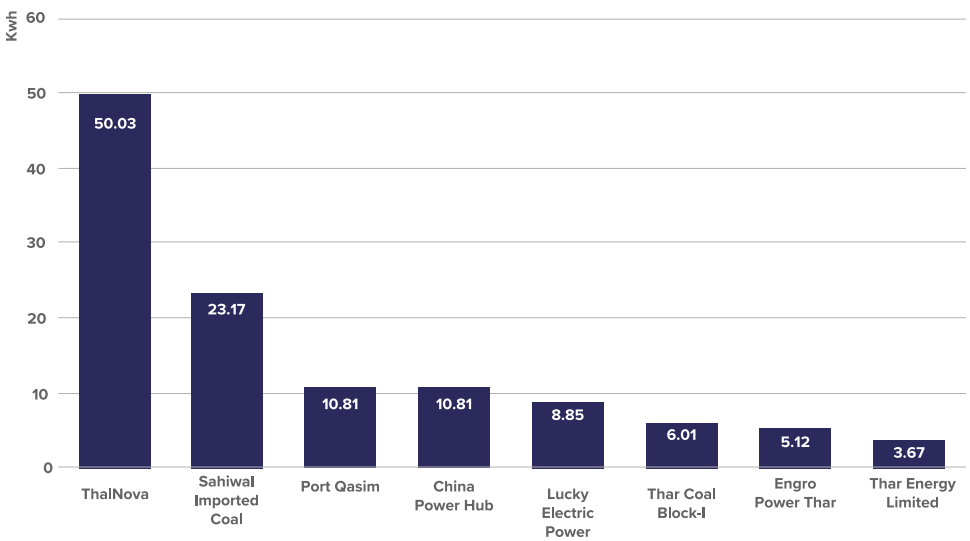
Figure 7 *Energy generated by CFPPs*



Capacity Payment per Unit on Energy Generated by CFPPs

Capacity payments per unit by each coal-fired power plant in Pakistan vary depending on factors such as plant efficiency, fuel costs, and contractual agreements with the government. These payments are typically structured to cover fixed costs associated with plant operation, maintenance, and financing, ensuring that power producers receive a steady revenue stream regardless of actual electricity generation. However, the specific amount of capacity payment per unit may differ among plants based on individual contract terms and market dynamics. The following graph shows the capacity payment per unit by each power plant.

Figure 8 *Capacity payment per unit (Kwh)*

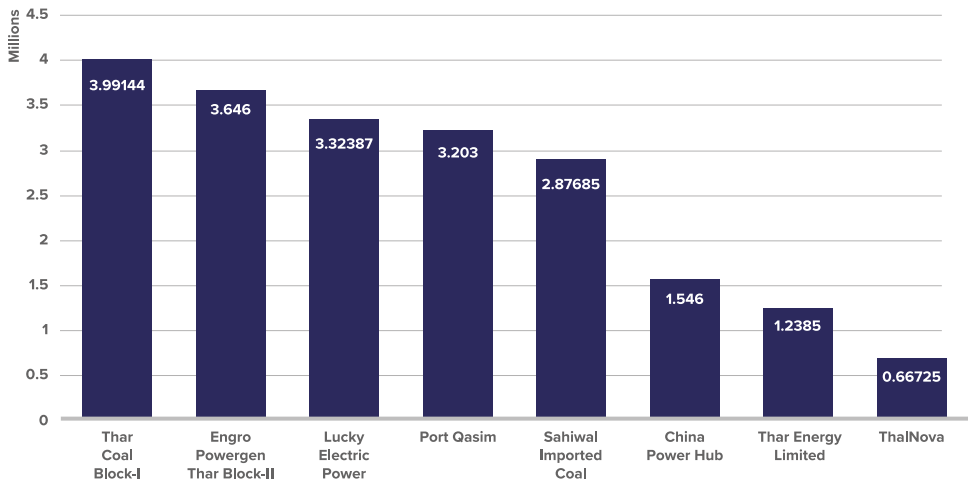


Emissions from CFPPs

The emissions stemming from coal plants in Pakistan present a pressing environmental issue, contributing to air pollution and exacerbating climate change concerns. Research conducted by Siddiqui et al. (2016) underscores the significant impact of these emissions on both local air quality and global atmospheric conditions. Additionally, a study by Farooqi et al. (2019) highlights the socioeconomic implications of transitioning away from coal. With Pakistan's considerable dependence on coal for energy generation, addressing these emissions remains paramount. The following graph shows the amount of emissions released from each coal fired power plants in FY 2022-23.

Emissions(tons) from CFPPs

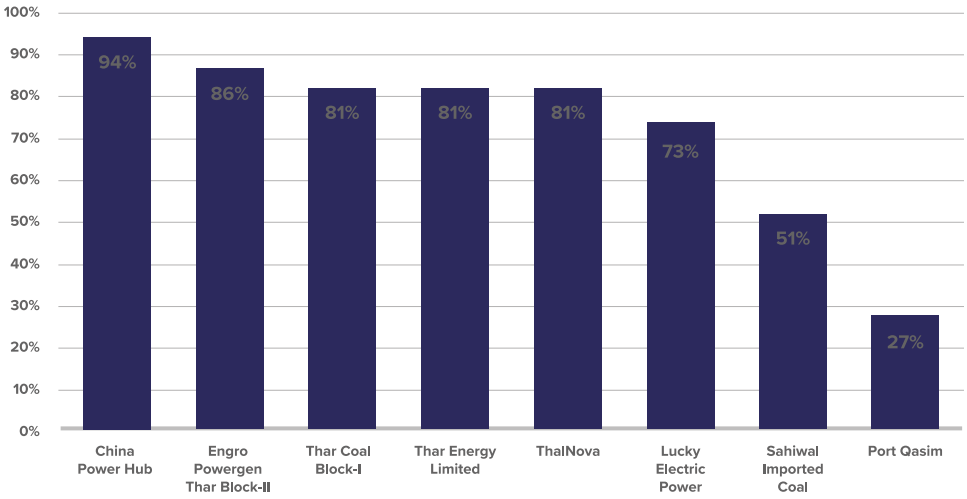
Figure 9



Utilization Rate of Energy from CFPPs

The utilization rate of energy generated from coal-fired power plants fluctuates based on various factors such as demand for electricity, maintenance schedules, and fuel availability. Generally, these plants aim for high utilization rates to maximize their operational efficiency and revenue generation. However, factors like grid instability, transmission constraints, low demand and fuel supply interruptions can impact the actual utilization rate. The following graph depicts the rate at which the energy is utilized from each coal-fired power plant.

Figure 10 *Utilization rate of energy produced from each CFPP*



Debt, Equity and Cost

Debt, equity, and the cost of coal-fired power plants are crucial components in assessing their financial viability and overall feasibility. Typically, these energy projects involve a combination of debt and equity financing, with debt often playing a significant role due to the high initial capital investment required. The cost of coal-fired power plants encompasses various expenses, including construction, equipment procurement, land acquisition, and operational expenses over the plant's lifecycle. Balancing debt and equity ensure a sustainable financial structure while considering factors such as interest rates, loan terms, and shareholder returns. The following table shows the debt, equity and cost of CFPPs in Pakistan.

Table 3 – Debt, Equity & Cost of each CFPP

	Debt Amount (Million USD)	Equity Amount (Million USD)	Capital Cost (Million USD)
Engro Powergen Thar Block –II	373.3	0	849
Sahiwal Imported Coal	1420.69	361.63	1597
Port Qasim	1555	427.44	1597
China Power Hub	1361.69	406.74	1597
Lucky Electric Power	717	0	767
Thar Coal Block I	1434	478	1597
Thar Energy Limited	373.3	130	424
Thal Nova	373.3	0	424

Impact of Coal Power Generation on Circular Debt:

Circular debt refers to the accumulation of unpaid bills within the power sector's supply chain, involving power generation, distribution, and transmission companies. In Pakistan, circular debt has been a longstanding issue; the capacity charges paid to the IPPs is one of the major contributors to the circular debt. The circular debt of the energy sector has reached a staggering Rs 5.422 trillion; capacity payments to IPPS have reached Rs 2 trillion and the Chinese power producers under CPEC is around Rs. 511 billion. This phenomenon leads to a vicious cycle where power sector entities struggle to pay their dues, resulting in financial constraints, operational inefficiencies, and disruptions in electricity supply.

Coal-fired power plants contribute to circular debt in several ways; Firstly, the **high capital costs.** Establishing coal power plants requires significant upfront investment, including infrastructure development, equipment procurement, and project financing. The substantial capital expenditure burdens power producers and utilities, exacerbating financial strain within the sector.

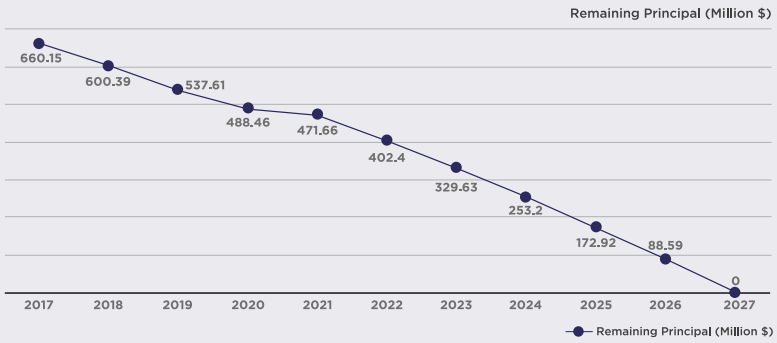
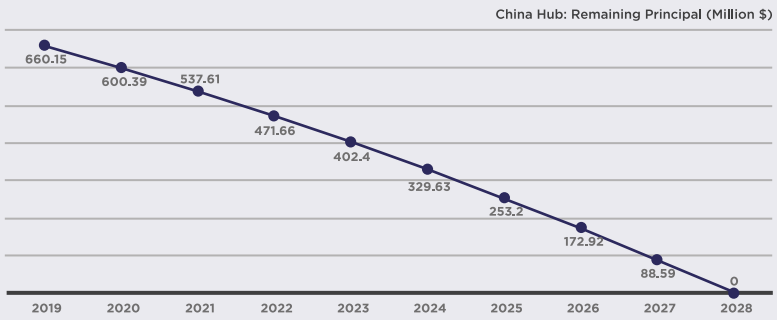
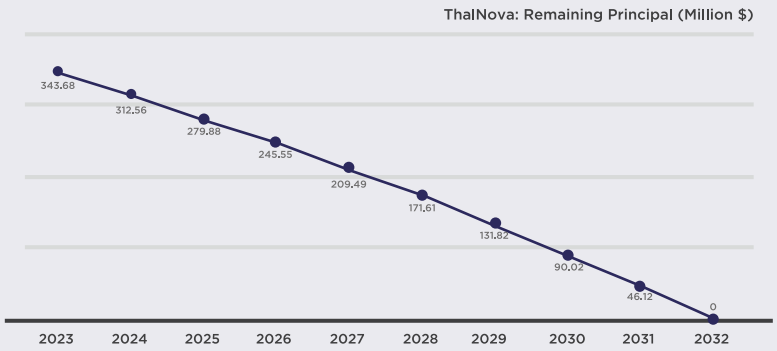
Secondly, the issue of fuel price volatility. Coal prices are subject to fluctuations in the global market, influenced by factors such as demand-supply dynamics, geopolitical tensions, and regulatory changes. Variations in coal prices can affect the operational costs of coal-fired power plants, impacting their profitability and financial sustainability. **Thirdly, operational challenges associated with c**oal power plants including maintenance requirements, fuel logistics, and environmental compliance costs. These factors can contribute to cost overruns, downtime, and reduced efficiency, further straining the financial viability of power generation companies.

Environmental externalities associated with coal power plants such as air pollution, water contamination, and greenhouse gas emissions. Addressing these environmental impacts requires investments in pollution control technologies and mitigation measures, adding to the operational expenses of coal power plants and utilities.

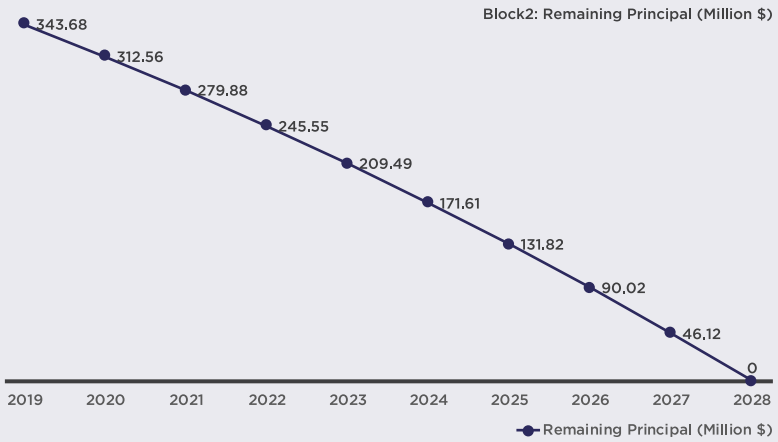
The Debt Analysis of Coal fired Power Plants

The debt analysis of coal-fired power plants in Pakistan necessitates a comprehensive understanding of various aspects related to their operation, efficiency, and environmental impact. One key aspect to consider is the performance of coal-fired power plants under different conditions. The economic viability and sustainability of these plants are crucial factors in debt analysis. Research by Stougie et al. (2018) highlights the profitability challenges faced by coal-fired power plants without subsidies, emphasizing the importance of financial considerations in the analysis. The following table represents the debt analysis of coal fired power plants in Pakistan.

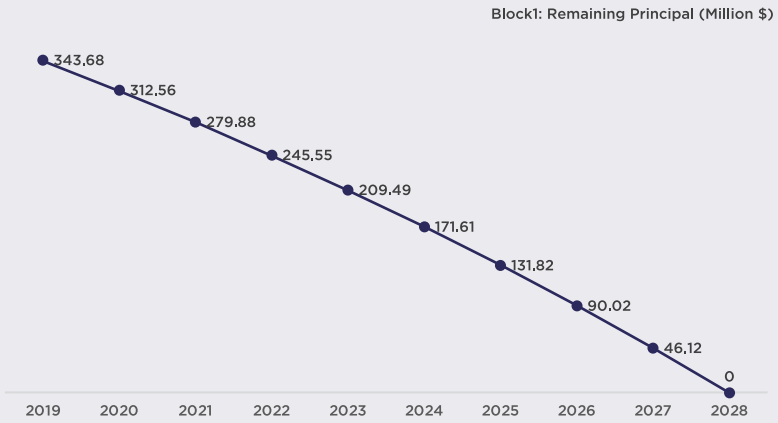
Table 2 - Debt Profile of CFPPs

Coal fired Power Plant	Debt Profile
The Sahiwal coal power plant has an outstanding principal debt of $555.1 million, which is to be paid off over a period of four years.	
The China Hub power plant faces a substantial financial obligation, with a principal outstanding amounting to $402.4 million USD over a period of five years. According to a study by Mahmood et al. (2019), investments in energy infrastructure, particularly those funded through foreign loans or investments, can significantly impact a country's economy and debt sustainability.	
The ThalNova coal power project carries a substantial financial commitment, with a principal outstanding amount of $328.3 million USD over a duration of nine years.	

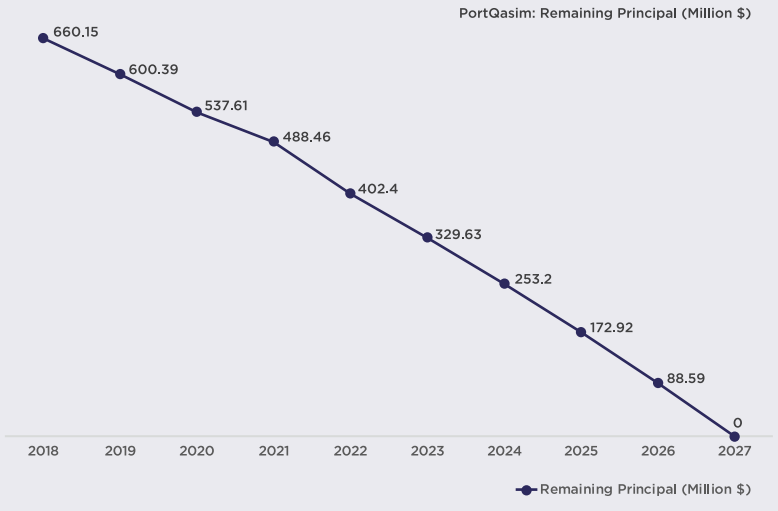
The Block2 power project has a principal outstanding amount of $456 million USD over a period of five years, linked to capacity payments. This underscores the financial intricacies involved in energy infrastructure projects and highlights the challenges associated with managing debt in the energy sector.



The debt analysis shows that Block 1 coal-fired power plant owe 630.6 million debt to be paid over the period of 5 years. As highlighted by Shah et al. (2020), continued reliance on coal-fired power plants like Block 1 not only perpetuates environmental degradation but also exacerbates financial strain due to high maintenance costs and associated debts.



Port Qasim holds a debt of $698.4 million, which is to be repaid over a period of four years. This debt represents a financial obligation that Port-Qasim owes to creditors or lenders.



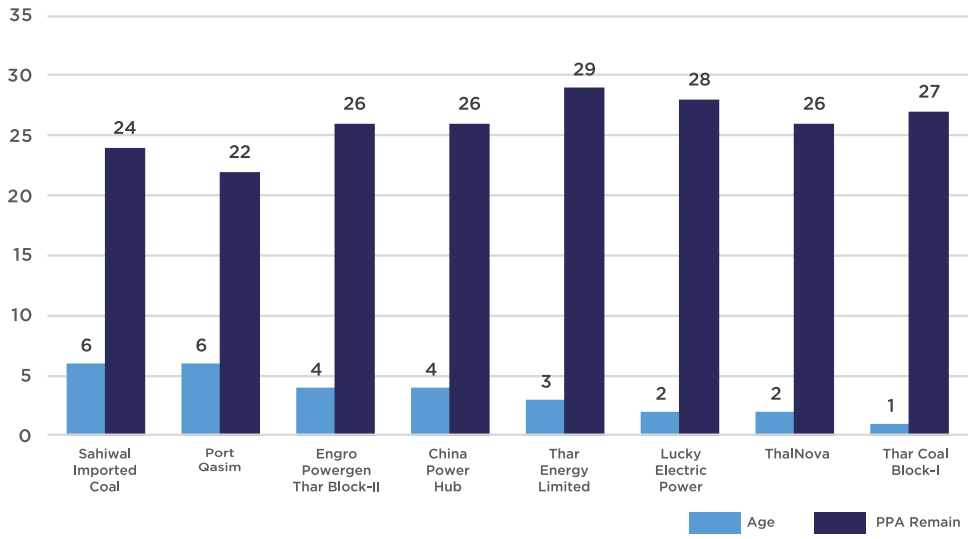
Lucky coal power plant has an outstanding principal debt of $246.4 million, which is to be repaid over a period of nine years.

The Thar Engro Coal Power Plant (TEL) stands as a substantial investment in Pakistan's coal-based energy infrastructure. Nonetheless, a recent examination of its debt unveils that TEL still owes a remaining principal amount of $320.5 million, to be paid off over a period of eight years. Hussain et al. (2020) highlighted that the high debt associated of TEL underscores the financial risks of coal-based projects, including operational challenges and environmental liabilities.

Age and Power Purchase Agreements of CFPPs

The coal fleet in Pakistan is young as presented in the graph below, the maximum age of some power plants is 6 years of operational lifespan. Understanding the age of coal fired power plants is crucial for assessing the potential for early retirement of these plants. Also, the government made long-term contractual agreements i.e. the Power Purchase Agreements (PPAs) with the producers. These agreements outline terms and conditions for the sale and purchase of electricity generated by the power plants. Analysing PPAs associated with coal-fired power plants involves examining the contractual obligations, pricing mechanisms, duration, and other terms stipulated in these agreements. Understanding PPAs provides insights into the financial viability, revenue streams, and long-term commitments of coal-fired power plants in Pakistan's energy market. The following graph shows the remaining PPA duration of coal fired power plants in Pakistan. The remaining PPAs pose financial burdens on the government and consumers alike, as they often entail fixed payments regardless of actual energy generation.

Age & Remaining PPAs Duration **Figure 5**



Overview of Law-and-Order Situation for Coal Mining in Pakistan

The law-and-order situation in Pakistan remains a significant concern, characterized by various challenges including political instability, insurgency, and criminal activities. Recent studies, such as the report by the Institute for Economics and Peace (IEP), highlight Pakistan's ranking as one of the least peaceful countries globally, with ongoing issues related to terrorism, sectarian violence, and organized crime (IEP Global Peace Index, 2021). These security challenges have pervasive effects across sectors, impacting economic development, social cohesion, and infrastructure projects. Additionally, the Pakistan Security Report 2020 underscores the persistent threat posed by non-state actors, particularly in regions with active militant presence, which further complicates efforts to maintain law and order (Pakistan Security Report, 2020).

Security Risks in Coal Mining Areas in Pakistan

Coal mining areas in Pakistan are particularly vulnerable to security risks, given their remote locations and susceptibility to militant attacks, criminal extortion, and vandalism. Various studies emphasize the significant impact of security threats on coal production and infrastructure development in regions like Balochistan and Khyber Pakhtunkhwa (PIPS Security Report, 2021). Instances of attacks on coal mining operations, including the recent incident in Machh, Balochistan, highlight the severity of security challenges faced by the coal industry. Moreover, issues related to land disputes, illegal mining activities, and inadequate enforcement of regulations have further complicated the situation. Such incidents disrupt coal supply chains, undermine investor confidence, and impede efforts to modernize and expand coal-related infrastructure.

Socio-economic Implications of Coal Mining

The law-and-order situation in Pakistan's coal mining areas exacerbates socio-economic challenges for local communities. Displacement, loss of livelihoods, and social unrest are common consequences of insecurity in these regions, as documented by studies such as the Human Rights Commission of Pakistan's (HRCP) annual reports (HRCP Annual Reports, various years). Moreover, the socio-economic vulnerabilities of coal mining communities are compounded by factors such as poverty, lack of access to basic services, and inadequate infrastructure (World Bank, 2020). The recent study by the Sustainable Development Policy Institute (SDPI) underscores the need for targeted interventions to address socio-economic disparities and enhance community resilience in coal mining areas (SDPI Report on Sustainable Development, 2021).

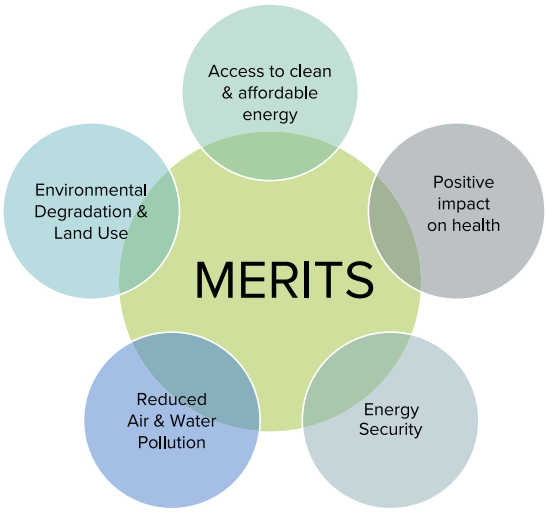
Environmental Concerns regarding Coal Mining

Security risks in Pakistan's coal mining areas also pose environmental challenges, including illegal mining practices, deforestation, and pollution. Studies by environmental organizations like the Worldwide Fund for Nature (WWF) highlight the detrimental impact of coal mining on ecosystems and biodiversity in regions such as Thar (WWF Pakistan). Furthermore, the lack of effective enforcement of environmental regulations exacerbates environmental degradation and health hazards for local populations (Environmental Protection Agency Pakistan). The recent report by the International Union for Conservation of Nature (IUCN) underscores the urgency of adopting sustainable mining practices and enforcing environmental safeguards to mitigate the ecological footprint of coal mining activities (IUCN Reports on Environmental Conservation).

04
The Merits of Transitioning Away from Coal

Transitioning away from coal in Pakistan presents multifaceted benefits, including but not limited to environmental, economic, and social dimensions. Environmentally, this shift mitigates the adverse impacts linked with coal combustion, such as air and water pollution and greenhouse gas emissions. Reductions in pollutants like nitrogen oxides, sulfur dioxide, and heavy particles lead to enriched air quality, public health, and ecosystem maintenance (Ahmed et al., 2019; Kumar et al., 2024). Economically, the transition offers opportunities for investment in cleaner, more sustainable energy sources like renewables and natural gas, promoting job creation, innovation, and economic diversification, while fading reliance on volatile fossil fuel markets (Ali et al., 2020; Shahbaz et al., 2024). Socially, transitioning away from coal bolsters energy security, as renewables offer distributed and resilient energy systems. Additionally, it addresses environmental justice concerns by reducing the disproportionate burden of pollution endured by disadvantaged communities near coal mines and power plants (Saeed et al., 2024; Malik et al., 2024). Overall, transitioning away from coal is vital for achieving a cleaner, healthier, and more sustainable energy future for Pakistan.

Figure 6 *Merits of transitioning away from coal*



Access to Clean & Affordable Energy

In Pakistan, access to clean and affordable energy is crucial for sustainable development, economic growth, and enhancing citizens' quality of life. The country grapples with challenges such as reliance on fossil fuels, inadequate infrastructure, and a large population without access to electricity. Transitioning towards cleaner energy sources, such as renewables like solar, wind, and hydroelectric power, presents an opening to address these encounters (Nawaz et al., 2019; Hussain et al., 2024). Investing in renewable energy infrastructure reduces greenhouse gas emissions and mitigates climate change impacts, besides extending energy security

by mounting the energy mix. Furthermore, promoting energy efficiency measures and adopting innovative technologies can help improve access to affordable energy for underserved communities while reducing overall energy demand. Overcoming barriers and accelerating the transition towards a cleaner and more sustainable energy future in Pakistan requires rigorous efforts from both public and private sectors (Saeed et al., 2021; Mahmood et al., 2024).

Energy Security through Diversified Energy Sources

Transitioning away from coal in Pakistan presents a substantial opportunity to enhance energy security by diversifying the energy portfolio and reducing reliance on imported energy supplies. As coal-fired power generation constitute a considerable bit of Pakistan's energy infrastructure, replacement to cleaner alternatives like renewables and natural gas can ease weaknesses associated with coal dependency. Renewable energy producers, including wind and solar, offer indigenous and sustainable energy options, reducing dependence on imported fuels and enhancing energy self-sufficiency for Pakistan. Furthermore, transitioning away from coal can lead to improved grid stability and resilience, as renewable energy technologies provide decentralized solutions. Additionally, reducing coal use aligns with global efforts to mitigate climate change, thereby reducing Pakistan's exposure to geopolitical risks associated with fossil fuel dependencies (Ali et al., 2020; Kumar et al., 2024).

Reduced Air and Water Pollution

Phasing down coal-fired power plants in Pakistan can lead to a significant reduction in air and water pollution. Phasing out coal-fired power plants can reduce CO2 emissions, positively impacting the environment and various aspects of society such as tax revenues, electricity grid structure, and international trade (Vögele et al., 2018). Studies have linked exposure to emissions from coal-fired power plants to respiratory conditions and reduced lung function in children (Amster & Levy, 2019). Closing coal-burning power plants has been associated with molecular and neurodevelopmental benefits in children, emphasizing the positive impact of reducing air pollution from such sources (Tang et al., 2014). Efforts to control air pollutants from coal-fired power plants, such as implementing control measures and policies, have been shown to be effective in reducing emissions of nitrogen oxides, sulfur dioxide, and particulate matter (Dai et al., 2019).

Positive Impact on Health

Transitioning away from coal in Pakistan has the potential to positively impact public health outcomes with favour to economy of Pakistan. Coal combustion is major producer of pollutants in country leading to several lungs' illnesses, cardiovascular diseases, and premature mortality. By phasing out coal-fired power plants and transitioning to cleaner energy sources like renewables and natural gases, Pakistan

can significantly reduce ambient air pollution levels, improving air quality and mitigating respiratory diseases' burden on public health (Ahmed et al., 2019; Nawaz et al., 2024). Moreover, reducing coal use decreases the release of toxic pollutants into water bodies, safeguarding water quality and reducing risks of waterborne diseases. Additionally, transitioning away from coal can lead to indirect health benefits by mitigating climate change impacts, which exacerbate health risks such as heat-related illnesses and vector-borne diseases (Javaid et al., 2019; Hussain et al., 2024).

Environmental Degradation and Land-use Sustainability

Transitioning away from coal in Pakistan presents an opportunity to mitigate environmental degradation and promote land-use sustainability. Coal mining and combustion contribute to significant land degradation through habitat destruction, soil erosion, and deforestation. Transitioning towards cleaner energy sources such as renewables and natural gas can help alleviate these pressures by reducing the demand for coal extraction and its associated environmental footprint (Khan et al., 2020; Malik et al., 2024). Renewable energy sources require minimal land use compared to coal mining and can be integrated into existing landscapes without significant disruption. Furthermore, transitioning away from coal reduces air and water pollution, safeguarding ecosystems and biodiversity. By prioritizing renewable energy development and transitioning away from coal, Pakistan can mitigate environmental degradation, promote land-use sustainability, and safeguard its natural resources for future generations.

05

Mapping the Factors for Transitioning away from Coal

Transitioning away from coal is crucial for countries aiming to mitigate environmental degradation, enhance energy security, and foster sustainable development. According to a report by the World Bank, Pakistan's reliance on coal for electricity generation contributes significantly to air pollution and greenhouse gas emissions, leading to adverse environmental impacts and public health concerns (World Bank, 2023). In addition to environmental concerns, Pakistan's energy sector faces challenges related to energy security and supply reliability. The country's dependence on imported coal makes it vulnerable to price fluctuations and supply disruptions in the global coal market (Ministry of Energy, 2021). Moreover, the burning of coal for electricity generation contributes to water scarcity issues in Pakistan, as it requires significant amounts of water for cooling purposes in thermal power plants (World Bank, 2023). These factors underscore the urgent need for Pakistan to transition away from coal and towards renewable energy sources.

The transition from coal to renewable energy sources in Pakistan is influenced by several key factors identified by researchers. One significant factor is the country's abundant renewable energy potential, which includes solar, wind, and hydropower resources. Pakistan's geographical location allows for ample sunlight, wind, and access to rivers, providing viable alternatives to coal-based power generation (Khan et al., 2023). Additionally, government policies play a crucial role in promoting renewable energy adoption. Initiatives such as the Alternative and Renewable Energy Policy aim to create a conducive regulatory environment for renewable energy development and investment, providing incentives such as feed-in tariffs and tax credits to encourage private sector participation (Ahmed et al., 2022). Global commitments, such as Pakistan's participation in international agreements like the Paris Agreement, further drive the transition away from coal and towards low-carbon energy sources (UNFCCC, 2021). Technological advancements in renewable energy technologies have also been identified as key factors facilitating the transition. Advances in solar panel design, wind turbine technology, and energy storage solutions have made renewables more affordable and efficient, contributing to their competitiveness compared to coal (IRENA, 2022).

Moreover, provincial initiatives play a crucial role in promoting renewable energy adoption in Pakistan. Provinces like Punjab, Sindh, and Khyber Pakhtunkhwa have implemented programs and projects to harness their renewable energy potential and reduce dependence on coal. Despite these enablers, several barriers hinder Pakistan's transition from coal to renewables, including infrastructure limitations, political interests, financial constraints, inter-provincial disparities, and policy uncertainty. Addressing these challenges and leveraging the identified enablers are essential for Pakistan to accelerate its transition to cleaner energy sources and achieve its sustainable development goals.

5.1. Enablers for Transition from Coal to Renewable Energy Sources

In this section, we'll discuss the factors in detail that facilitate the transition from coal to renewables. From technological advancements to policy frameworks and market dynamics, understanding these factors is crucial in navigating the shift towards sustainable energy sources.

Global Commitments:

As a signatory to international agreements such as the Paris Agreement, Pakistan is under increasing pressure to align its energy policies with global efforts to combat climate change and reduce greenhouse gas emissions. The commitments outlined in the Paris Agreement necessitate a transition towards low-carbon energy sources, compelling Pakistan to re-evaluate its reliance on coal and prioritize cleaner alternatives (UNFCCC, 2021). This global imperative reinforces Pakistan's resolve to phase out coal and accelerate the adoption of renewable energy technologies. By embracing sustainable energy solutions, Pakistan not only fulfils its international obligations but also mitigates the adverse impacts of climate change, enhances energy security, and fosters economic growth through the development of a resilient and diversified energy sector.

Government Policies and Initiatives:

Government policies are instrumental in driving the transition from coal to renewable energy, with initiatives like the Alternative and Renewable Energy Policy serving as cornerstones in creating a regulatory framework conducive to the advancement and investment in renewable energy. This policy framework not only outline guidelines but also provides incentives such as feed-in tariffs and tax credits, which play a pivotal role in stimulating private sector involvement and investment in renewable energy projects. As highlighted by UNESCAP (2023), these proactive measures are essential in bolstering the transition towards sustainable energy sources, fostering innovation, and reducing dependency on fossil fuels. By implementing such policies, governments can accelerate the deployment of renewable energy technologies, thereby contributing to global efforts to combat climate change and achieve energy security.

Growing Public Awareness:

The increasing public awareness about the detrimental effects of coal combustion on the environment and human health serves as a significant driver for transitioning away from coal in Pakistan. As communities become more educated about the consequences of fossil fuel reliance, there is a rising demand for cleaner and more sustainable energy alternatives. The increasing shift towards distributed solar generation indicates the growing awareness of the public. This increasing

awareness not only creates pressure on policymakers to prioritize renewable energy initiatives but also fosters a societal shift towards embracing cleaner energy sources.

Abundant Renewable Resources:

Pakistan is endowed with substantial renewable energy potential, comprising solar, wind, and hydropower resources. The country's favourable geographic positioning ensures abundant sunlight, wind, and access to rivers, facilitating the generation of renewable energy. A study by Song et al. (2023) underscores the vast opportunities presented by Pakistan's natural landscape for harnessing clean energy sources. This potential not only enables the diversification of the energy mix but also promotes sustainability and mitigates environmental impacts associated with conventional fossil fuel-based energy sources. As Pakistan endeavours to meet its increasing energy demands while addressing environmental concerns, the development of renewable energy infrastructure stands as a promising avenue for achieving energy security and reducing carbon emissions in the long term.

Technological Advancements:

Recent advancements in renewable energy technologies have significantly enhanced their affordability and efficiency, marking a pivotal shift towards sustainable energy solutions. Innovations across various sectors, including solar panel design, wind turbine technology, and energy storage solutions, have played an important role in bolstering the competitiveness of renewable energy sources. Breakthroughs in solar panel efficiency and durability, coupled with declining manufacturing costs, have substantially lowered the overall cost of solar energy generation. Similarly, advancements in wind turbine design, such as taller towers and longer blades, have led to increased energy capture and improved performance in varying wind conditions, further driving down the cost of wind power. Additionally, innovations in energy storage technologies, including battery storage systems and grid-scale storage solutions, have addressed intermittency challenges associated with renewable energy sources, enhancing their reliability and enabling greater integration into existing energy grids. These advancements, as highlighted by the International Renewable Energy Agency (IRENA, 2022), underscore the transformative potential of renewable energy technologies in reshaping the global energy landscape, driving sustainable development, and mitigating the impacts of climate change.

Provincial Initiatives:

Provinces in Pakistan are actively pursuing initiatives to foster the adoption of renewable energy within their jurisdictions, with notable efforts exemplified by Punjab's implementation of the Punjab Green Development Program. This program stands as a testament to the province's commitment to sustainable development

and the promotion of renewable energy sources. Punjab Green Development Program to encourage the use of renewable energy sources (UNESCAP, 2023). By incentivizing and facilitating the deployment of renewable energy technologies, Punjab aims to reduce its reliance on fossil fuels, mitigate environmental degradation, and enhance energy security. Through this program, the province not only seeks to harness its abundant renewable energy potential but also stimulate economic growth, create employment opportunities, and improve the overall quality of life for its residents. The Punjab Green Development Program aligns with broader national objectives outlined in Pakistan's energy policies and international commitments to combat climate change, demonstrating proactive measures at the sub-national level to drive the transition towards a cleaner and more sustainable energy future.

Declining Costs of Renewable Energy Technologies:

The declining costs of renewable energy technologies, including solar panels, wind turbines, and energy storage solutions, have significantly contributed to the feasibility of transitioning away from coal in Pakistan. Technological advancements and economies of scale have led to substantial cost reductions, making renewables increasingly competitive with fossil fuels. As the cost of renewable energy continues to decline, Pakistan can leverage these affordable clean energy technologies to accelerate its transition towards a more sustainable energy future.

5.2. Inhibitors to Transition from Coal to Renewable Energy Sources

Infrastructure Limitations:

Pakistan faces challenges related to insufficient transmission and distribution infrastructure for renewable energy integration. The lack of grid connectivity in remote areas hampers the scaling up of renewable energy projects (World Bank, 2023).

Political Interests:

Political interests tied to the coal industry may hinder policy reforms and investment in renewable energy. Coal-dependent regions and stakeholders lobby against renewable energy initiatives, slowing down the transition process (Iqbal, 2022).

Financial Constraints:

Limited access to financing and subsidies for renewable energy projects poses a significant barrier to their development. High upfront costs and the lack of affordable financing options deter investors from committing to renewable energy ventures (IMF, 2021).

Policy Uncertainty:

Inconsistent government policies and regulatory frameworks create uncertainty for investors in the renewable energy sector. Frequent changes in energy policies

undermine investor confidence and hinder long-term planning (Asian Development Bank, 2022).

Lack of Public Awareness and Education:

Despite Pakistan's efforts to raise awareness about renewable energy, significant gaps in public understanding persist. According to a survey conducted by the Sustainable Development Policy Institute (SDPI) in 2023, only 30% of respondents were aware of the benefits of renewable energy, while 70% lacked a comprehensive understanding of its importance. This lack of awareness contributes to a passive stance among the public regarding the urgency of transitioning away from coal. Without widespread public support, policymakers may face less pressure to prioritize renewable energy initiatives, hindering progress towards a cleaner energy future.

Inadequate Technology Transfer and Innovation:

Pakistan's renewable energy sector is provided with limited access to cutting-edge technologies due to challenges in technology transfer and innovation. According to the Pakistan Council of Renewable Energy Technologies (PCRET), only 20% of renewable energy projects in the country incorporate state-of-the-art technologies, with the majority relying on outdated or inefficient systems. Barriers such as intellectual property rights restrictions and limited collaboration with international technology providers impede the adoption of innovative renewable energy solutions. Without access to advanced technologies, Pakistan may struggle to effectively transition away from coal and optimize its renewable energy potential.

Insufficient Regulatory Frameworks:

The absence of robust regulatory frameworks and institutional capacity poses significant challenges to Pakistan's renewable energy development. According to a report by the National Electric Power Regulatory Authority (NEPRA), regulatory inefficiencies and delays affect approximately 40% of renewable energy projects, resulting in increased costs and project abandonment. Furthermore, a shortage of skilled personnel within regulatory agencies exacerbates these challenges, with only 30% of regulatory staff possessing specialized knowledge in renewable energy. Strengthening regulatory frameworks and enhancing institutional capacity are critical to overcoming these barriers and facilitating the transition away from coal.

Challenges in Land Acquisition and Site Identification:

Land acquisition for renewable energy projects faces hurdles related to ownership disputes, environmental concerns, and competing land-use priorities. According to the Ministry of Climate Change, approximately 50% of proposed renewable energy projects encounter delays or cancellations due to land acquisition issues. Additionally, the lack of clear procedures for site identification and environmental

impact assessments further complicates project development. Streamlining land acquisition processes and implementing transparent site identification criteria are essential to overcoming these challenges and accelerating the deployment of renewable energy infrastructure.

Limitations on Integration of Renewable Energy into Existing Grid Infrastructure:

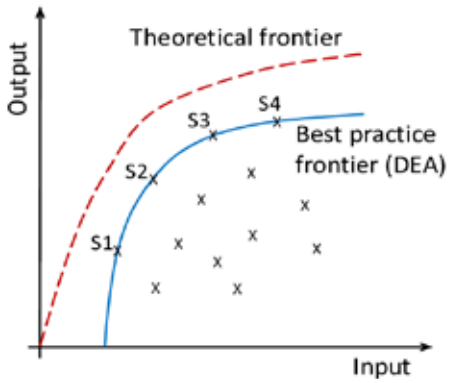
Pakistan's energy infrastructure is inadequately prepared to accommodate the large-scale integration of renewable energy sources into the grid. Only 15% of the national grid's capacity is currently compatible with renewable energy inputs. The intermittent nature of renewable energy sources exacerbates grid stability concerns, with renewable energy accounting for only 5% of total electricity generation due to limitations in energy storage and distribution. Investing in grid modernization, energy storage technologies, and demand-side management strategies is crucial to maximizing the contribution of renewable energy and facilitating the transition away from coal.

06

Data Envelope Analysis (DEA) based Ranking of CFPPs for Retirement

To build a ranking for early retirement of coal-fired power plants in Pakistan, Data Envelope Analysis (DEA) is used in this study. DEA is a mathematical methodology whereby linear programming is employed to quantitatively assess the relative efficiency of a set of entities considering multiple criteria simultaneously. It evaluates the efficiency of decision-making units (DMUs) such as businesses, public services, or any entities that convert inputs into outputs. DEA compares the relative efficiency of DMUs by constructing a frontier of best practices.

DEA was originally derived from a concept of efficiency measurement, defined as the ratio between the weighted sum of outputs to the weighted sum of inputs. It is important to note that these weights are varied and optimized for each entity, enabling each entity to achieve its best possible efficiency score (Cooper et al., 2007).



Functional Forms of DEA

The basic functional form of DEA can be represented mathematically in two ways: the input-oriented and output-oriented models. We have employed Input-Oriented Model.

Input-Oriented DEA Model

The input-oriented model aims to minimize inputs while maintaining the same level of outputs. The linear programming formulation can be expressed as follows:

Objective Function

Minimize $Minimize\ \emptyset$

Subject to:

$$\sum_{j=1}^{n} \frac{u_i y_{ij}}{v_k x_{ik}} \leq 1 \quad for\ all\ i$$

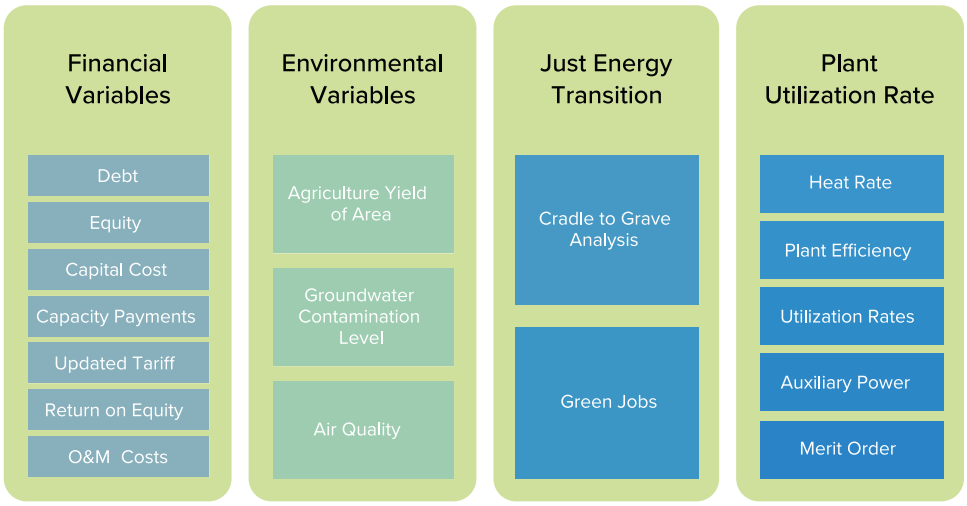
$$u_j \geq 0, v_k \geq 0$$

$$\emptyset \geq 0$$

Where:

- $\emptyset$: Efficiency score (inverted) of the DMU under evaluation (should be minimized).
- x_{ik}: Amount of input x used by DMU i.
- y_{ij}: Amount of output y produced by DMU i.
- u_i: Weight given to output y.
- v_k: Weight given to input x.

To achieve an equitable and just energy transition, careful planning and execution are essential to avoid perpetuating historical injustices and creating new ones (Kime, 2023). The ranking for retirement of CFPPs presented in this section is based on the following variables.



By using the above input variables for analysis, the DEA method provides the following ranking for retirement of the coal fired power plants.

Ranking of CFPPs for retirement **Figure 11**

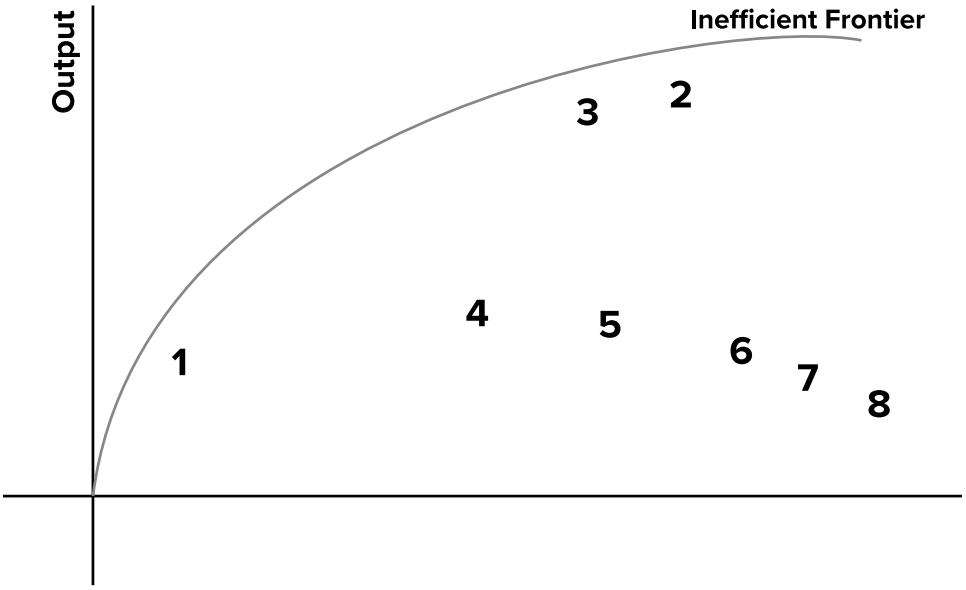


Table 4 - Ranking of CFPPs for retirement

Coal fired Power-plant	Ranking
Sahiwal Imported Coal	**1**
China Power Hub	**2**
ThalNova	**3**
Engro Powergen Thar Block –II	**4**
Thar Energy Limited	**5**
Port Qasim	**6**
Thar Coal Block-I	**7**
Lucky Electric Power	**8**

According to the DEA results, Sahiwal imported coal power plant is ranked first for early retirement based on the efficiency score, environmental impact, and economic viability. Various studies propose that for early retirement of CFPPs, following parameters are used that include operating efficiency, age and air pollution (Maamoun er al., 2020). The CFPPs that underperform when assessed on various technical, economic, and environmental criteria are also suggested to be the suitable plants for early retirement (Cui et al., 2021). Following closely behind Sahiwal, the China Power Hub plant ranks second for early retirement.

6.1. The Retirement Case of Sahiwal Coal Power Plant

As mentioned in the above section, the DEA based analysis ranked the Sahiwal coal power plant on priority for early retirement. To validate this ranking, a Discounted Cash Flow (DCF) Analysis of the Sahiwal coal power plant was done, which is a financial evaluation method used to estimate the value of an investment by discounting future cash flows to their present value and the environmental impact of phasing out the power plant.

In case of Sahiwal coal power plant, the DCF analysis reveals that if we retire the Sahiwal power plant after **10 years**, the projected value of power plant's cash flows would be an estimated **0.874 billion USD.** The environmental estimates highlight that if we retire the power plant after **10 years**, we can reduce **48 $MtCO_2$.** And, if we **immediately** retire the power plant, the current value will be **1.633 billion USD.** Retiring the power plant immediately, would save up to **65 $MtCO_2$** which is equal to **1.36 billion USD Carbon Credits.**

Supporting Mechanisms for Transitioning away from Coal

Just Energy Transition Partnerships (JETPS)

The Just Energy Transition Partnerships (JETP's) provides a framework for accelerating the process of phasing-out the fossil fuels. It establishes intergovernmental partnerships with G7 countries to provide the financial and technical support. The goal of JETP's is to harmonize the national climate goals with net-zero emissions targets; these partnerships encourage investments in renewable energy sources while managing the shift away from fossil fuels.

The JETPs can act as a bridge to fill the gap between developed and developing countries for transitioning away from fossil fuels and for low-carbon development. JETP funds mobilize finance from different sources for targeted and catalytic phasing down of fossil fuels. These partnerships could be solution for Pakistan to transition from coal to renewables. These partnerships are tailored according to the needs of the recipient country and involves the local decision makers.

Energy Transition Mechanism (ETM)

The Energy Transition Mechanism by Asian Development Bank facilitates the phasing down of CFPPs in developing countries. In Pakistan's case, the total installed capacity exceeds the peak demand which provides an opportunity to retire the underutilized coal plants in areas where overcapacity exists as it will not impact the energy security situation. The Sahiwal coal power is under ETM discussions for early retirement. Pakistan signed ADB's ETM to evaluate early retirement of coal power plants.

Coal Transition Accelerator

At COP26, the international community decided to expedite the phase-down of coal. Coinciding with the Powering Past Coal Alliance (PPCA) announcement, France, together with Canada, European Commission, Indonesia, Malaysia, Senegal, United Kingdom, United States, Vietnam, and several organizations including the PPCA have launched the Coal Transition Accelerator. It intends to share expertise, design new policies including the best practices and lessons learned and unlock new sources of public and private financing to facilitate just transitions from coal to clean energy.

The initiative consists of three pillars: a **strategy** to decrease the cost of capital for the investment in clean energies in developing and emerging markets, to be developed by the World Bank. Secondly, a **Coal Transition Commission** that will propose options and solutions to unlock new sources of public and private financing for transitioning the existing unabated coal fleet. Then, a "**gold standard**" to measure and assess the climate and financial risks attached to private sector investments in new coal assets, to be developed by the OECD, with the support of the IEA.

Coal To Clean Credits

The Coal to Clean Credit Initiative (CCCI) aim to incentivize a just transition away from coal plants to clean energy in Emerging markets and Developing Economies (EMDE's). The CCCI provides support for just and equitable transition plans that invests in reskilling of workers and creates new employment opportunities for the communities that previously relied on the fossil fuels economy for their livelihoods.

The CCCI receives funding from the Rockefeller Foundation and has partnered with ACEN Corporation to investigate a pilot project in the Philippines that would use carbon finance to replace CFPPs with renewable energy sources while preserving the livelihoods of those who are most in need. This innovative project provides guidance for the CCCI's global coal plant phase-out plans in compliance with the Paris Agreement.

Lessons from UK's Coal to Clean Journey

The UK's complete phase-out of coal power generation offers invaluable lessons for other nations that face unique challenges in phasing out coal:

- **Ambitious Decarbonization Targets:** The UK's commitment to phase out coal by 2025, announced nearly a decade in advance, provided clear direction for long-term planning.
- **Market Reforms and Carbon Pricing:** The introduction of carbon pricing and market reforms helped create a competitive environment for renewables, driving investments in clean energy.
- **Policy Support for Wind Power:** Strong government support for wind energy in particular was a cornerstone of the UK's renewable energy success.
- **Investments in Grid Infrastructure:** Modernizing the electricity grid was essential to accommodate growing renewable energy generation and maintain grid stability.
- **Just Transition:** The UK's approach ensured that the transition was just, providing support for coal workers and communities through retraining programs and social support measures.

07
Policy Recommendations

For orderly retirement of coal power plants in Pakistan, a comprehensive policy approach is required. Transitioning away from coal can have significant environmental and health benefits. The adoption of alternative energy sources such as renewables have the potential to replace coal-fired power plants. Additionally, repurposing coal plant sites for renewable energy generation, energy storage systems, and other sustainable sources can facilitate a smooth transition away from coal (Huang et al., 2021).

Moreover, it is crucial to evaluate the existing power plants and their operational lifetimes of coal plants under climate goals and considering the political economy of policy options for an orderly retirement of coal fired power plants. Based on the empirical analysis, mentioned above in the previous chapter, the following policy recommendations are crafted for an orderly, equitable and just energy transition for phasing down the coal fired power plants in Pakistan.

Policy Recommendations	Relevant Stakeholders	Time Frame
The Government of Pakistan should collaborate with the Chinese coal fired power plant owners and other relevant Chinese & Pakistani stakeholders and involve the Chinese government as well to devise a medium to long-term strategy for an orderly retirement of coal fired power plants based on economic feasibility. The strategy should have ambitious coal exit targets.	Ministry of Energy (Power Division) Ministry of Planning Development and Special Initiatives (MoPD &SI) Belt and Road Initiative Green Coalition (BRIGC), Ministry of Commerce of the People's Republic of China (MOFCOM), Ministry of Ecology and Environment of the People's Republic of China (MEE), Chinese Power Plant Owners, Relevant Pakistani Stakeholders	Short term
The Government needs to renegotiate the Power Purchase Agreements (PPAs) with the coal power generation plants as the existing PPAs are leading to a high circular debt. The restructuring should be done in such a manner that PPAs encourage the coal to renewables transition and encourage repurposing of these coal fired power plants.	Ministry of Energy (Power Division) Ministry of Planning Development and Special Initiatives (MoPD &SI) Belt and Road Initiative Green Coalition (BRIGC), Ministry of Ecology and Environment of the People's Republic of China (MEE) Power Plant Owners	Short term

The establishment of Just Energy Transition Partnerships (JETPs) with effective targeting for an orderly retirement of coal power plants can provide the mechanism to transition away from coal and can accelerate the adoption of renewable energy through incentive mechanism.	Governments of the countries in JETPs, Relevant Ministries (Ministry of Energy {Power Division, Pakistan), G7 Countries, Coal Power Plant Owners, Private sector of the other countries involved in agreement	Short term
The Energy Transition Mechanism (ETM) provides a facilitating framework that is tailored according to country's need. Through ETM, coal plant owners can make a deal that matches their interests in transitioning from coal to renewables.	Ministry of Energy (PD), Coal Power Plant Owners, Asian Development Bank	Short to Medium term
The Government needs to devise concise policies for power wheeling as it will help in accelerated adoption of renewable energy and will address the issue of limited grid capacity.	Ministry of Energy (Power Division), National Electric and Power Regulatory Authority (NEPRA), Central Power Purchasing Agency (CPPA-G)	Short term
The Government should devise a policy framework that addresses the challenges of provinces by making targeted policies for each province in transitioning towards renewable energy.	Private Power and Infrastructure Board (PPIB), Ministry of Energy (Power Division), NEPRA	Short-term
The Government should develop a carbon pricing mechanism to measure the implicit cost for coal power generation. Introducing a carbon pricing system, such as a carbon tax or emissions trading, would impose additional financial costs on coal plants. The Coal to Clean Credit Initiative (CCCI) is designing a methodology that can be used to accelerate the managed and equitable phase-out of coal plants and incentivize their full or partial replacement with clean power in this decade.	Ministry of Planning, Development, and Special Initiatives (MOPD&SI), Ministry of Climate Change and Environmental Coordination (MoCC&EC), National Electric Power Regulatory Authority (NEPRA), Private Power and Infrastructure Board (PPIB)	Short to medium term

Implementing a Carbon Border Adjustment Mechanism (CBAM) can incentivize Pakistan's transition away from coal by levying tariffs on carbon-intensive industries. It will encourage domestic industries to shift from coal to renewables.	Ministry of Energy (Power Division), Ministry of Planning Development and Special Initiatives (MoPD & SI), Ministry of Finance (MoF), Board of Investment (BOI)	Short-term
Public-private partnerships should be encouraged in China and Pakistan for transitioning towards clean energy sources. The private sector can play an important role in accelerating investment in renewable energy as well as private-public partnerships and joining initiatives to finance large-scale renewable energy projects.	Private Financing Advisory Network (PFAN), Ministry of Energy (Petroleum Division), Ministry of Planning, Development, and Special Initiatives (MOPD&SI), Ministry of Commerce of the People's Republic of China (MOFCOM), Development Finance Institutions (DFI) CSOs	Short to medium term
A platform should be established where all the relevant stakeholders can actively share their perspectives and can collectively devise a methodology for phasing down coal and accelerating the adoption of renewables.	Ministry of Planning, Development, and Special Initiatives (MOPD&SI), National Development and Reform Commission of China (NDRC), Chinese & Pakistani Civil Society Organizations	Short term to medium term
A comprehensive plan should be developed to modernize Pakistan's energy grid to ensure the integration of renewable energy sources efficiently while reducing the reliance on coal-fired power plants. This plan should include investments in grid capacity, smart grid technologies, and energy storage systems.	Ministry of Energy, Government of Pakistan, National Electric Power Regulatory Authority (NEPRA), Power Distribution Companies (DISCOs), International Financial Institutions	Medium term

Regional and international cooperation in the South-Asia region can play an important role. International collaboration and coordination can help in speeding up the adoption of best practice policies related to transitioning away from coal and collective achievement of key benchmark targets.	South Asian Countries, Chinese Stakeholders, Relevant ministries from regional countries MoPD & SI (Pakistan) Ministry of Energy (Power Division, Pakistan) CSOs	Medium term
Develop a capacity building program aimed at rapidly expanding targeted capacity development through collaboration with community, research institutions and industry associations. Moreover, foster partnerships with leading Chinese entities in the renewable technology sector, who are well-versed in Pakistan's local conditions, to facilitate joint ventures.	Ministry of Planning, Development, and Special Initiatives (MOPD&SI), Ministry of Commerce of the People's Republic of China (MOFCOM), CSOs (Pakistani & Chinese)	Short term

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ABOUT THE AUTHORS

Zainab Babar

Zainab Babar is working as a Research Associate at SDPI. With over five years of professional experience, she specializes in energy modelling, energy planning, and policy analysis. She has a strong focus on energy security, innovative financing for energy transitions, and household energy efficiency. Her expertise lies in analyzing policy frameworks for both macro and micro-level energy transitions.

Dr. Khalid Waleed

Dr Khalid Waleed is a PhD in Energy Economics. With more than 10 years of experience in Pakistan's Energy Sector, his expertise includes Energy Markets, Energy Poverty, Energy Transition (Macro and Micro level) Sustainable Future Resources, Carbon Markets, Emission Trading, Long Term Macroeconomic sustainability, and Econometrics. He is a vocal advocate for integrating sustainable energy and environmental considerations into economic policies. He has authored a book and published several research papers on topics such as energy transition, regional integration, distributed generation, community-based solutions, carbon markets, and demand-side management.

SDPI
Sustainable Development Policy Institute

Plot # 10, Taimur Chambers,
Fazl-ul-Haq Rd, G-6/2 Blue Area,
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