Danish Energy Agency

Pakistan's power sector towards 2045

Scenarios supporting Pakistan's long-term energy planning for a greener future

November 2023

Copyright

Disclaimer

This brief analysis report is written by the Danish Energy Agency based on a modelling of the Pakistani power sector conducted in close cooperation between the Danish Energy Agency, the Pakistani energy authorities, and Ea Energy Analyses. All parties have cooperated and contributed to the analysis.

Contacts

Nadeem Niwaz, Danish Energy Agency, nni@ens.dk

Marie Bredkjær Thomsen, Danish Energy Agency, mabt@ens.dk

Foreword

It is my privilege to present this analysis report, as part of the cooperation efforts between Denmark and Pakistan in pursuit of sustainable and resilient long-term energy solutions. As we navigate the challenges posed by climate change, this report stands as a testament to our commitment to supporting Pakistan in achieving its ambitious alternative and renewable energy goals.

The Danish Energy Transition Initiative (DETI) has been key in facilitating the partnership between our nations. This report unveils a comprehensive long-term power sector model, meticulously developed to strengthen Pakistan's ambitious renewable energy policy targets. Our primary aim is to provide solid insights and choice awareness for the country's long-term sustainable energy planning, not merely as a means to meet its Nationally Determined Contributions (NDCs) for the energy sector but to support Pakistan in exploring avenues for exceeding these commitments.

I am pleased that the outcomes of this endeavor will be shared at a dedicated joint side-event during COP28 in the United Arab Emirates. This event seeks to stimulate discussions on the pivotal role of renewable energy in Pakistan's energy transition and its crucial contribution to climate change mitigation. Not the least, it will underscore the imperative of international cooperation and assistance in navigating the challenges inherent in transitioning from black to green energy sources.

In the spirit of international cooperation and shared responsibility, Denmark is looking forward to continue on this journey under DETI together with Pakistan, seeking solutions that will shape a cleaner, more sustainable future for Pakistan and the world.

Kristoffer Böttzauw

Director General, Danish Energy Agency

Executive summary

This brief analysis report investigates the development of Pakistan's power sector within the context of global climate objectives outlined in the Paris Agreement, considering the country's financial circumstances. Utilizing the Balmorel least cost optimization model, four scenarios are examined: Baseline, Net Zero 2050, Capital-restricted, and Net Zero Capital-restricted.

While the Net Zero 2050 scenario aims for cost-effective strategies to achieve net-zero emissions towards 2050, the Capital-restricted scenario optimizes the energy generation portfolio based on annual capital availability, reflecting Pakistan's economic situation. The Net Zero Capital-restricted scenario emphasizes the challenging balance between net-zero emissions and capital constraints.

The study reveals trends in electricity generation, highlighting a decrease in fossil fuel share, except in the Capital-restricted scenario. The Net Zero Capital-restricted scenario faces challenges meeting demand due to limitations in deploying renewable energy, posing the highest risk of load shedding. This emphasizes the need for strategies aligning financial constraints with sustainability goals.

Renewable energy shares vary in 2045, with the Net Zero 2050 scenario heavily investing in both wind and solar to optimize long-term cost-effectiveness and reliability. The Capital-restricted scenario leans towards thermal power plants, emphasizing coal and Re-Gasified Liquefied Natural Gas (RLNG) due to capital constraints.

Generation system costs differ across scenarios, with the Capital-restricted scenario being the most expensive, dominated by fuel costs. CO_2 emissions show divergence after 2030, with the Net Zero 2050 scenario experiencing a rapid decline, unlike the Baseline and Capital-restricted scenarios.

The scenarios suggest a net-zero power system requires significant wind investments in the Pakistani context. Use of new nuclear power generation, is considered inefficient and expensive, suggesting exploration of alternative options such as inter-weekly storage, flexible hydro scheduling, and demand response. The reliance on thermal power plants using coal and RLNG remains in scenarios without a net-zero target, posing economic vulnerabilities and risks.

Recommendations include increased efforts for renewable energy deployment, investments in the transmission grid, and flexibility solutions in the short and long term. Additionally, it is recommend that Pakistan seeks international partnerships, including financing and technical advice for long-term de-carbonization efforts of the power sector, considering Pakistan's commitments to the Paris Agreement and potential challenges in achieving carbon reductions without external support.

Table of Contents

Introduction

In 2020, the Pakistani government approved an ambitious policy on Alternative and Renewable Energy (ARE). This strategic initiative outlines a transformative shift, aiming to elevate the contribution of renewable energy sources in the national energy mix. The plan sets forth a trajectory to escalate the share of renewable energy from approximately 4% in 2018 to 30% by 2030. This target aims for a distribution of two-thirds solar and one-third wind energy. By 2030, the vision is for 60% of Pakistan's total electricity generation to stem from clean sources, encompassing all renewable energy sources including hydropower.

This brief analysis report centers on the crucial task of supporting Pakistan in the execution of its ambitious ARE policy. To support this endeavor, the Danish Energy Agency, the Pakistani energy authorities, and Ea Energy Analyses have developed a comprehensive long-term power sector model, with the primary goal of supporting policy targets beyond 2030 towards 2050. The overarching objective is to provide insights for Pakistan's long-term energy planning, not only outlining achievable paths to fulfill its NDCs for the energy sector but also investigating opportunities to enhance these commitments.

In the global context of striving for the climate goals laid out in the Paris Agreement, there is an increasing consensus that the energy sectors worldwide must undergo full de-carbonization. This study delves into the evolution of Pakistan's power sector within this overarching framework, carefully taking into account the nations' specific circumstances and challenges.

The study comprises four scenarios. The Baseline scenario serves as a reference. The Net Zero 2050 scenario aligns with the International Energy Agency's (IEA) net-zero-by-2050 pathway. The Capital-restricted scenario reflects Pakistan's economic situation based on data from Pakistan's Indicative Generation Capacity Expansion Plan (IGCEP). Lastly, the Net Zero Capital-restricted scenario emphasizes how achieving net-zero emissions towards 2050 with capital constraints in the power generation sector will affect the country's power system.

In the following sections of this report, we delve into the intricate details of these scenarios, providing an understanding of the pathways and strategies that can propel Pakistan toward a sustainable and low-carbon energy future.

Abbreviations

ARE	Alternative and Renewable Energy
COP28	28th Conference of the Parties (United Nations Climate Change Conference)
DETI	Danish Energy Transition Initiative
IEA	International Energy Agency
IGCEP	Pakistan's Indicative Generation Capacity Expansion Plan
NDC	Nationally Determined Contributions
NTDC	National Transmission & Despatch Company
PV	Photovoltaic
RLNG	Re-Gasified Liquefied Natural Gas

1. Scenarios and data

This study looks into the development of Pakistan's power sector within the context of a world achieving the climate objectives defined in the Paris agreement – adjusted to consider the financial circumstances of Pakistan. The four scenarios encompassed in this study are developed with the Balmorel least cost optimization model.

The Baseline Scenario provides a reference point for comparison. Next, the Net Zero 2050 scenario focuses on identifying cost-effective strategies for energy generation to achieve the ambitious sustainability goal of reaching net-zero emissions towards 2050, aligning with the IEA's net-zero-by-2050 pathway.

The Capital-restricted scenario investigates an optimized energy generation portfolio, considering the annual capital available for the power generation sector suggested by Pakistani energy authorities, e.g. the National Transmission & Despatch Company (NTDC), reflecting Pakistan's economic situation based on IGCEP data.

Finally, the Net Zero Capital-restricted scenario combines elements of the climate and economic objectives, presenting a scenario that seeks a balance between achieving net-zero emissions towards 2050 and considering the capital constraints of the power generation sector.

	Description	CO_2 emission limit	Available capital for generation expansion
Baseline (Reference)	Business as usual – no policy implemented	Unlimited	Unlimited
Net Zero towards 2050	Least cost optimization	IGCEP Balmorel's limit in 2032 converges linearly to 0 in 2050	Unlimited
Capital-restricted	Capital-restricted	Unlimited	2032 limit is based on the average investment per year from IGCEP, fixed until 2050
Net Zero towards 2050 Capital-restricted	Combined scenario reaching net zero emissions (in 2050 in a capital-restricted reality	IGCEP Balmorel's limit in 2032 converges linearly to 0 in 2050	2032 limit is based on the average investment per year from IGCEP, fixed until 2050

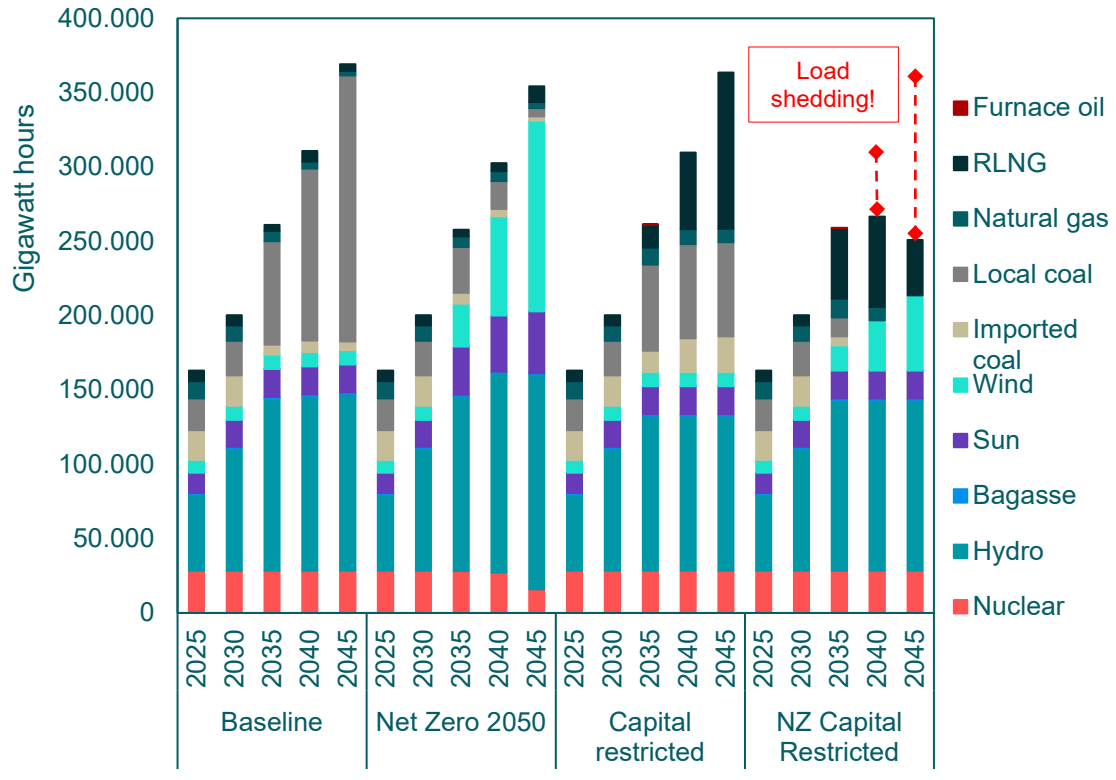
1. Results: Balancing climate objectives with economic constraints

1.1. Electricity generation: the role of fossil fuels and the risk of load shedding

In the following, only modelling results up to 2045 are shown for all scenarios since the technology options for Pakistan's power sector beyond 2045 are uncertain. Further analysis is required to suggest a sustainable pathway up to 2050.

As can be seen from the below figure, the total electricity production increases in all scenarios. This is due to the growing population and economic development of Pakistan. The share of fossil fuels in the generation mix decreases in all scenarios except for the Capital-restricted scenario. Fossil fuels (particularly natural gas and coal) play a significant role in the Baseline and Capital-restricted scenarios, accounting for 52% and 27% of total generation in 2045, respectively. In the Net Zero 2050 scenario, fossil fuels are almost phased out completely in 2045.

Figure 1: Electricity generation incl. loading



In the Net Zero Capital-restricted scenario, a pivotal challenge arises as installed capacity falls short of meeting growing demand. The scenario, though ambitious, carries the highest risk of load shedding due to constraints on deploying renewable energy caused by financial limitations. This

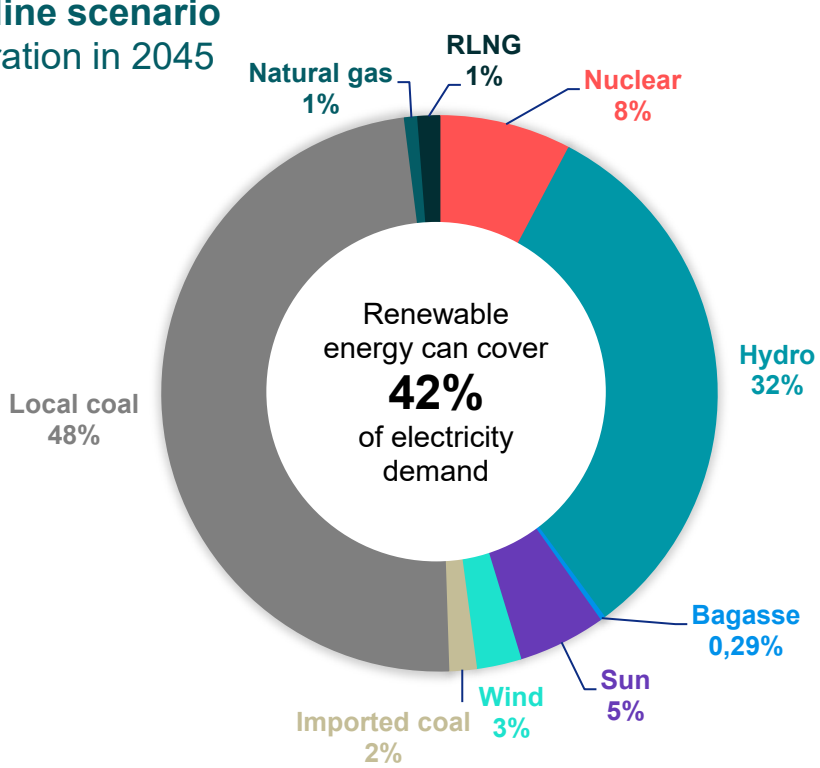
heightened risk stems from the potential inability of the power system to meet demand during periods of increased variability in renewable energy production. This underscores the delicate balance needed when pursuing net-zero goals within limited capital resources, emphasizing the necessity for carefully tailored strategies aligning financial constraints with sustainability objectives.

Recognizing the implications of the Net Zero Capital-restricted scenario, subsequent chapters will focus on the three remaining scenarios: Baseline, Net Zero 2050, and Capital-restricted.

1.2. Renewable energy share in electricity production in 2045

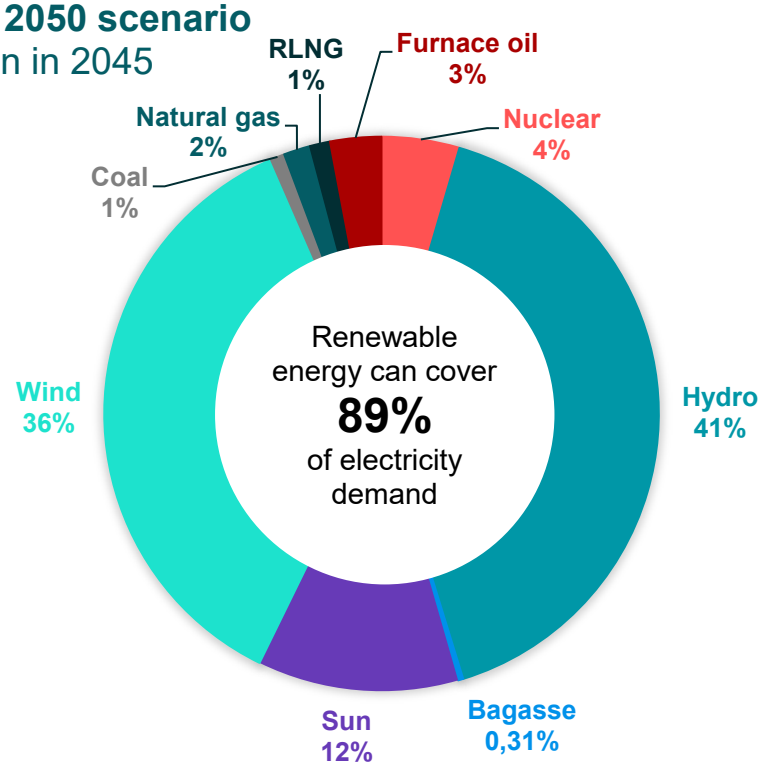
In the Baseline scenario, wind and solar energy will account for 5% and 3% respectively of the total electricity generation in 2045. This is a small decrease from the current share of about 6% and below Pakistan's target of 30% for renewable energy excluding hydro by 2030. The total share of renewable energy in 2045 including hydro is 42%, which also indicates that Pakistan will not reach the countries renewable energy targets if the country continues on the current track.

Figure 2: Baseline scenario
Electricity generation in 2045



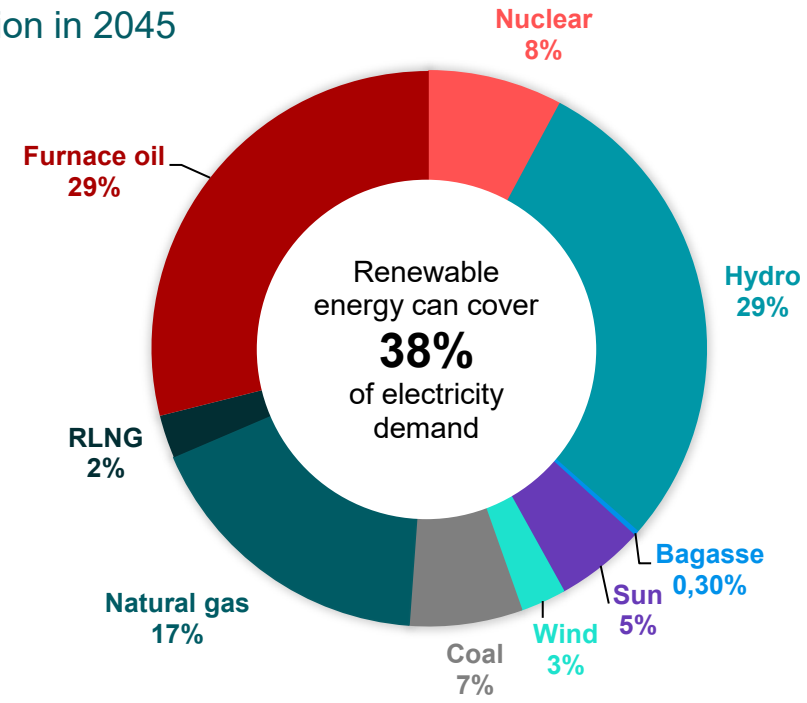
In the Net Zero 2050 scenario, the least-cost solution includes significant investments in wind and solar capacity. This scenario has the highest wind penetration, which reaches 36% of total generation in 2045. The share of solar reaches 12% while the total share of renewable energy will reach 89% of the total electricity generation in 2045. This is a significant increase from the current share and well above Pakistan's target of 30% renewable energy excluding hydropower and a total of 60% renewable energy including hydro by 2030.

Figure 3: Net Zero 2050 scenario
Electricity generation in 2045



Conversely, in the Capital-restricted scenario, the energy mix leans heavily towards thermal power plants, particularly relying on coal and RLNG. These choices are influenced by capital constraints and pragmatic considerations in meeting energy demands. In this scenario, wind and solar energy will account for 5% and 3% respectively while the total share of renewable energy reaches 38% in 2045. If this scenario is being realised, Pakistan will thus not be able to meet their targets.

Figure 4: Capital-restricted scenario
Electricity generation in 2045



Thus, Pakistan is set to achieve renewable energy targets in the Net Zero 2050 scenario, but faces challenges in the Baseline and Capital-restricted scenarios, hindering the realization of these goals within the designated period.

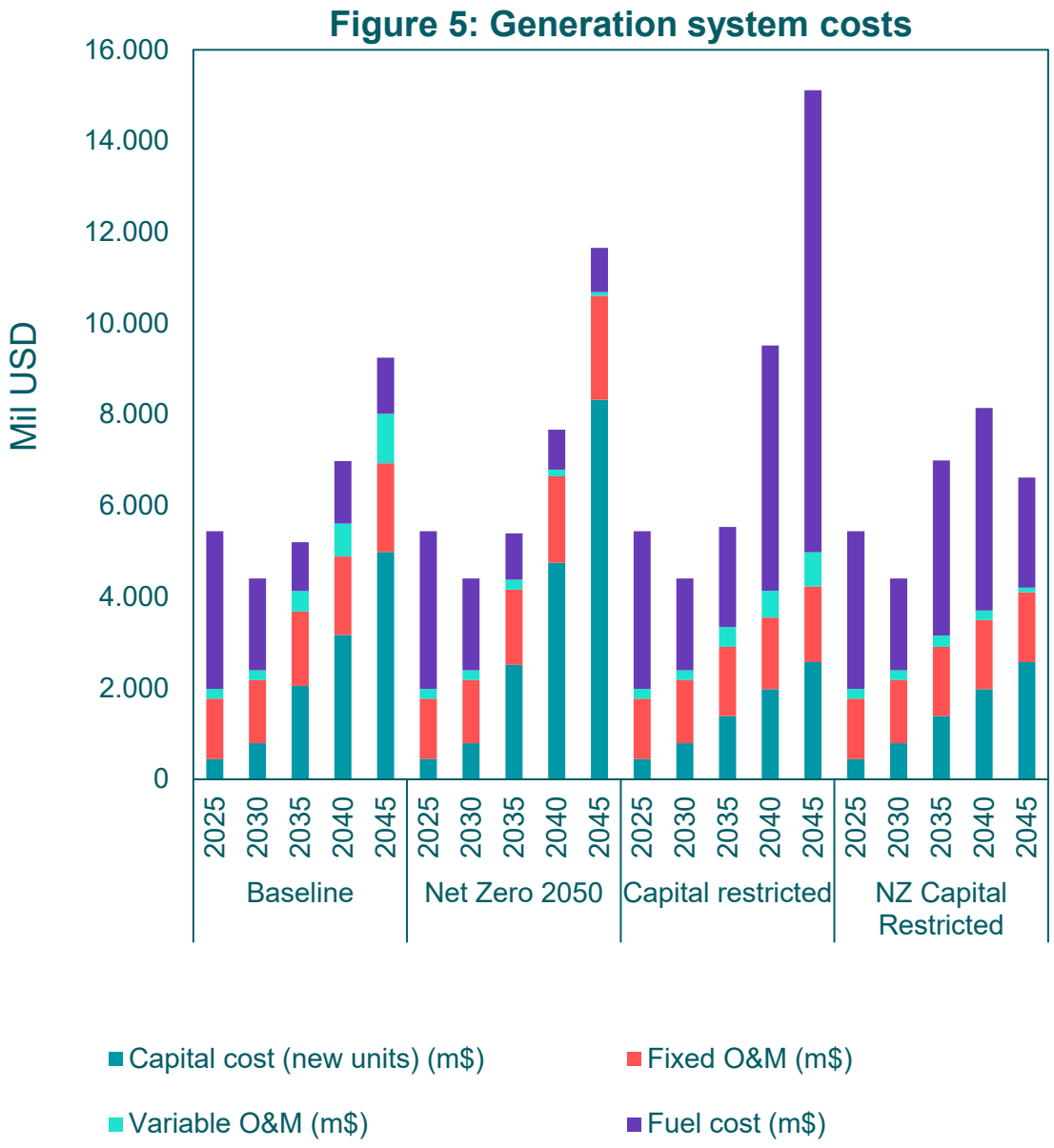
1.3. Generation system costs: a capital-restricted future is expensive

The power generation costs varies across the three scenarios. The Baseline scenario is the least expensive scenario, as it does not require any significant investment in renewable energy or other low-carbon technologies.

The power generation costs are highest in the Capital-restricted scenario, with the costs dominated by fuel costs. The other three scenarios have lower costs, but comparable high fuel costs – making the power system vulnerable to price shocks.

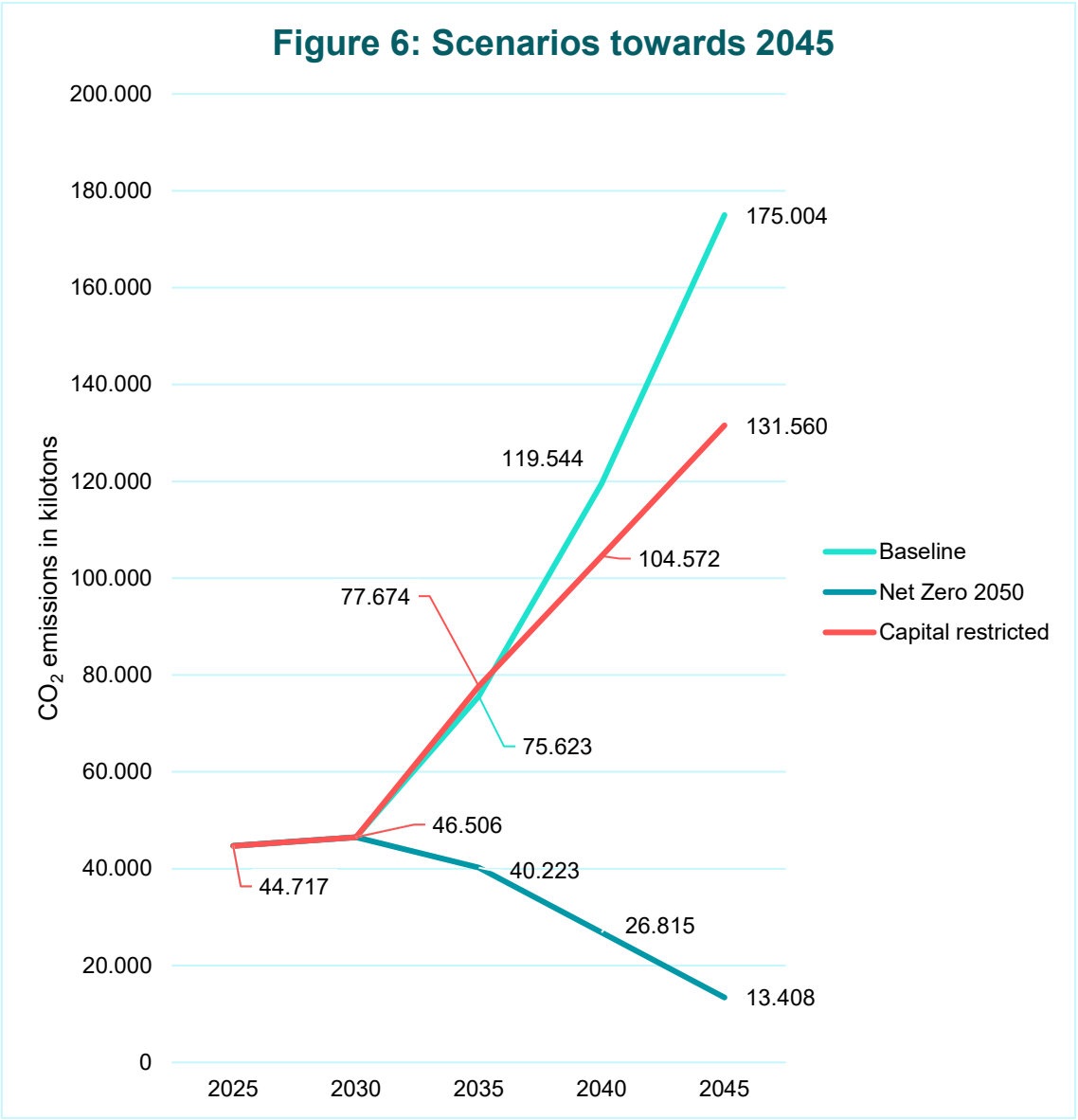
When looking at the fuel consumption, if no net-zero target is set, the system is highly dependent on coal in the Baseline scenario and on RLNG when there is a restriction on available capital. The cost of the Net Zero 2050 is dominated by the capital cost of the new investment in renewable energy technologies to reach the CO_2 target.

The power system costs do not reflect the implicit costs that load shedding and long-term dependency on fossil fuels have on the economy as a whole.



1.4. CO_2 emissions diverge after 2030

As can be seen from the below figure, the Net Zero 2050 scenario shows a rapid decline in emissions. On the other hand, the Baseline and the Capital-restricted scenario shows a continued increase in emissions and in none of these scenarios, the emissions have peaked before 2045.



The main reason for these different emission curves for the three scenarios is the role of fossil fuels, which continue to play a dominant role in the energy mix in the Baseline and Capital-restricted scenario towards 2045.

2. Conclusion

2.1. Implications

A net zero power system can be achieved with an energy mix that is mainly built on renewable energy resources. In the Pakistan power system model, the net zero pathway requires large investments in wind, since solar photovoltaic (PV) is not available in the evenings and during the night and there are limited options for storage. Hydropower will continue to play a central role towards 2045.

To meet the demand in the Net Zero 2050 scenario in periods of low wind and hydropower availability, it will be central to look into storage options, more flexible hydro scheduling, or demand response. Such strategic combinations will optimize cost-effectiveness while ensuring reliable coverage for varying demand conditions.

Under the assumption that Pakistan continues to have only very limited capital for capacity investment available, the energy mix will be largely dominated by thermal power plants using coal and RLNG, which will play a crucial role especially towards 2045. If the energy sector is not trying to meet the net zero target, the dependency on fossil fuels remains high until the end of the modelling period. Not only does this make Pakistan's energy sector more vulnerable to price shocks, but given that many other countries are introducing carbon pricing and trying to prevent carbon leakage, a long-term dependence on fossil fuels could have a negative impact on Pakistan’s economy as a whole.

If the country commits to a net zero target under the limited capital availability, Pakistan could face a large amount of unmet energy demand.

2.2. Recommendations

Pakistan is a signatory to the Paris agreement, however, given its local circumstances it seems that Pakistan could face difficulties to achieve the necessary carbon reductions from the power sector without substantial international support, including financing and technical advice. The scenario-analysis shows that without a net zero target, the energy sector would continue to depend heavily on fossil energy for a long time.

In the short-term, Pakistan should consider to increase the efforts to further deploy renewable energy and combining it with flexibility solutions, e.g., inter weekly storage, more flexible hydro scheduling and demand response options, while looking to international partnerships to support the longer term de-carbonization of the power and energy system.

Further analysis should be conducted to develop a technology catalogue for the Pakistani power system beyond 2045 to suggest a sustainable pathway to carbon neutrality in 2050 or later.

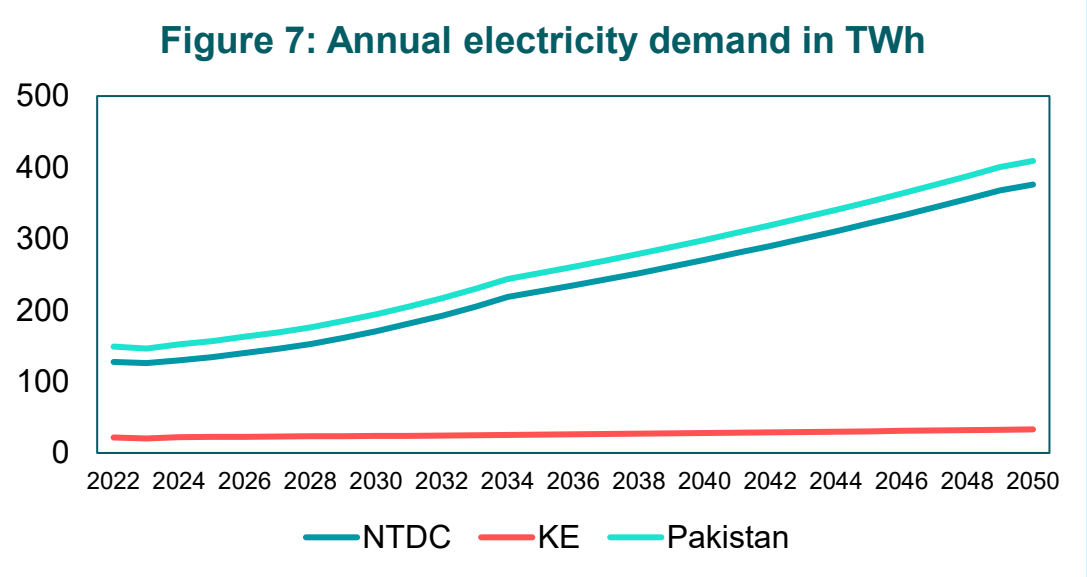
Appendix: Data and assumptions

The data foundation for this brief analysis report relies on IGCEP for input data from 2022 to 2031, covering existing and committed capacities. Updated demand data from the NTDC from 2022–2050 and fuel price projections indexed to the IEA 2022 onward diverge from IGCEP. The model extends to 2050 based on long-term assumptions, ensuring a comprehensive and forward-looking analysis. The following assumptions were made in order to populate the model until 2050, especially when looking beyond 2031.

Data	Assumptions
Demand profiles (2031-2050)	As of 2031
Resource profiles	As of 2031
Resource potential	As of 2031
Transmission capacity expansion	Net Transmission Capacity between NTDC and K-Electric is the same from 2031 to 2050 (2050 MW)
Generation system discount rate (annuity)	10% (same till 2050)
Transmission system discount rate	10% (same till 2050)

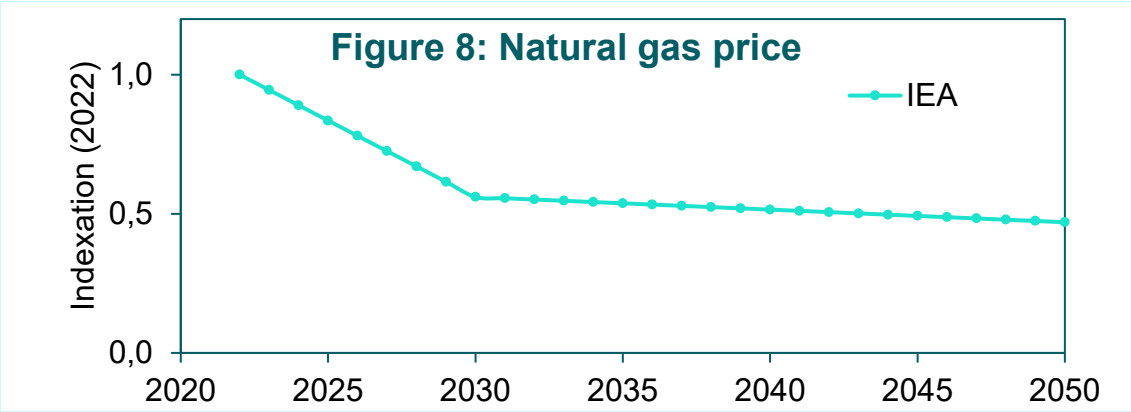
Annual electricity demand assumptions

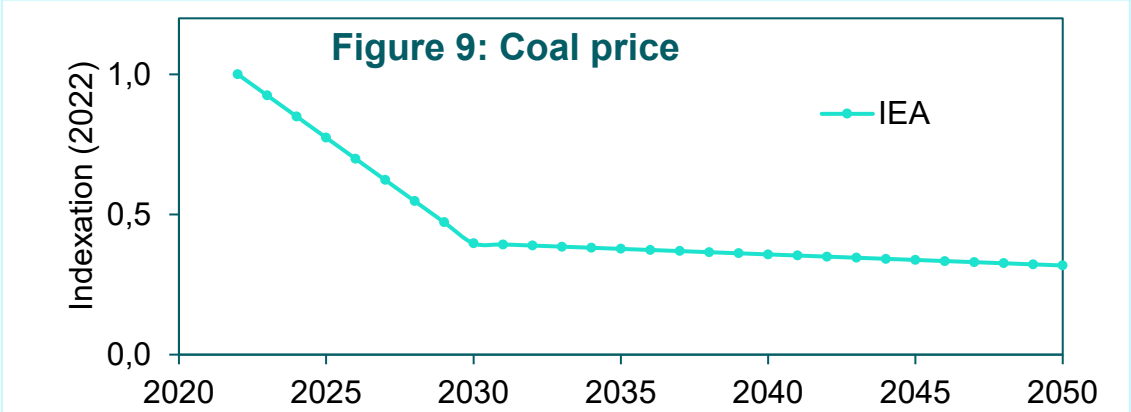
The annual electricity demand has been updated and does not correspond to the IGCEP data, as there are now more up-to-date demand data and forecasts available from NTDC, which differ significantly from the IGCEP data. Due to the recent electricity price increase, the assumptions for the future demand are lower compared to IGCEP 2022-2031.

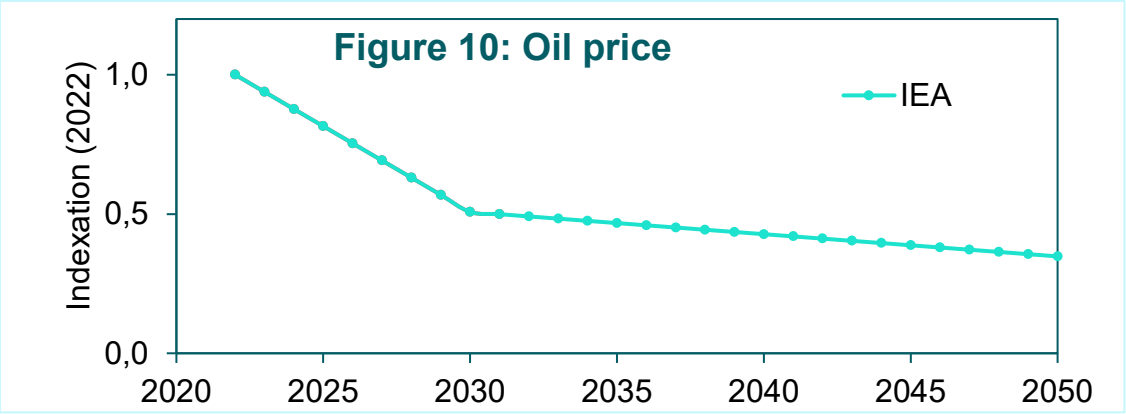


Fuel price assumptions

Fuel price assumptions for coal, natural gas and oil are assumed in line with the fuel price indexation from the latest IEA World Energy Outlook 2022, considering IEA Net Zero 2050 scenario. Starting price in the model in 2022 is the given price from NTDC, then indexed based on the trend visible in the graphs on the right.







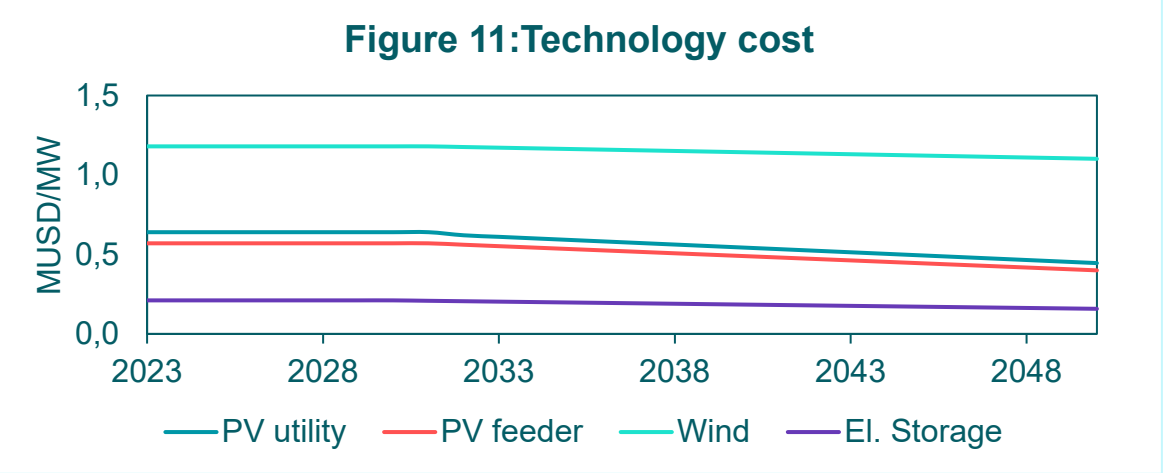
A different approach was adopted for price assumptions of uranium and bagasse, which are not defined in the IEA WEO 2022. The uranium price is assumed to being relatively stable in a report by IEAE-IEA. Therefore, the IGCEP trend is kept until 2050, as the trend respects the IEA assumption.

Technology cost reduction

For candidate generation technologies we are assuming the same investment cost, F-O&M, V-O&M pertaining to each respective technology until the end of IGCEP study horizon

For utility PV and wind, the technology costs are reduced starting from 2031 according to learning rates based on the IEA Net Zero Emissions by 2050 scenario.

As an additional technology, we introduced a lithium-ion electricity storage in 2031 with learning rates according to the Indonesia technology catalogue, as this is the newest available data for countries of the global south.



Take or Pay contracts have been signed in Pakistan for the use of fuels as natural gas and coal. It is known that certain contracts run beyond 2031. However, to simplify the transition between the take-or-pay regime towards a spot market type of fuel purchasing, a modelling assumption was implemented so that the take-or-pay contracts are not considered anymore after 2031.

Danish Energy Agency

November 2023