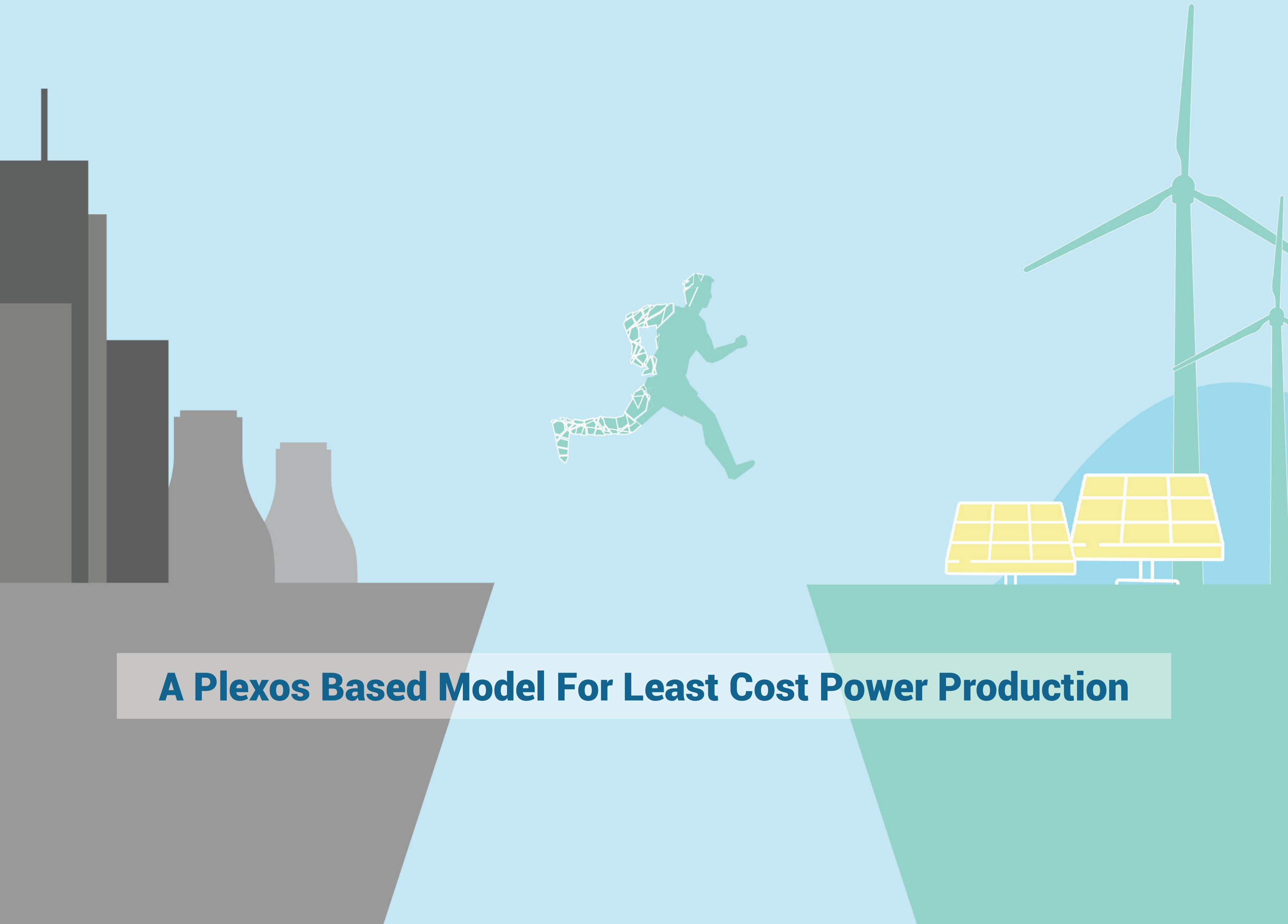
PRIED
Policy Research Institute
for Equitable Development

RENEWABLES FIRST

POWERING PAKISTAN'S FUTURE

Pathways to Optimize Affordable Electricity Generation



A Plexos Based Model For Least Cost Power Production

Powering Pakistan's Future

Pathways to Optimize Affordable Electricity Generation

A Plexos Based Model For Least Cost Power Production

About Us

Renewables First (RF) is a think-and-do tank for energy and environment. RF's work addresses critical energy and natural resource issues with the aim to make energy and climate transitions just and inclusive. We offer research, advocacy, planning and project management assistance to our partners. With the ambition to drive energy transition through impactful research, advocacy, and strategic partnerships, we envision an energy system in Pakistan that is environmentally sustainable, equitable, and powered by indigenous renewable energy resources.

Policy Research Institute for Equitable Development (PRIED) is a think-tank committed to sustainable and equitable development and a low carbon future. We produce high quality research to partake in and promote a global discourse on transition to renewable sources of energy; institutionalize interaction between all energy sector stakeholders in Pakistan; provide regulatory input, policy critique and research support to the parliament, government departments, aid organizations and international financial institutions; and organize events for networking and information-sharing.

Acknowledgements

We acknowledge the support of all partner organizations, government & private entities and independent energy experts who have made this study possible. We are especially thankful to the National Power Control Center (NPCC) for facilitating some of our data requirements.

Disclaimer

Most of the data used in this study has been gathered from publicly available resources such as the IGCEP (Indicative Generation Capacity Expansion Plan), the State of Industry Report 2022, Tariffs and Licenses available on NEPRA's website. While our team has been extremely cautious in carrying out this process as well as in making any assumptions with regards to missing data, the respective organizations do not assume any liability or responsibility for any financial or other loss resulting from the use of this data and results.

Lead designer: Sana Shahid
Co-designer : Shafaq Nasir

Our Team

Ammar Qaseem is a Fulbright scholar who is working on national electricity generation modelling on PLEXOS, large-scale VRE integration, RE auctions and the CTBCM transition. He is passionate about improving power sector planning, consistent implementation of policies and strong domestic markets which can go hand in hand with socio-economic growth.

Shaheera Tahir is a Researcher at Policy Research Institute for Equitable Development. She holds a Masters' degree in Public Administration with concentration in Energy and Environment from Columbia University. She has over 6 years of experience in RE project development, project finance, and policy research along with strong financial analysis and modelling skills and a thorough understanding of renewable energy developments.

Mustafa Amjad is an energy and climate change researcher from Pakistan, with a Mechanical Engineering MS graduate from University of Massachusetts, Amherst specializing in Renewable Energy and Policy. A Fulbright scholar, an Agora Energiewende fellow, a certified systems engineering professional and a Climate Reality leader, Mustafa has been actively involved in the transition towards a greener future for Pakistan.

Manzoor Ahmed Alizai is a research associate at Policy Research Institute for Equitable Development (PRIED). He holds a B.Sc. in Mechanical Engineering from University of Engineering & Technology (UET), Peshawar and M.Sc. in Energy Systems Engineering from National University of Sciences & Technology (NUST) Islamabad. His research work includes, power system planning, renewable energy integration, off- grid electrification, thermal generation technologies, Energy Finance and climate change.

Hammad Ali is an electrical power engineer, currently working as Project Coordinator at Renewables First. He has worked on Pakistan's first ever National Electricity Plan, Strategic Roadmap for DISCOs, Financial Models of future IPPs, and Power Purchase Price (PPP) forecast in the past. He is proficient in power system planning using PLEXOS, including modeling, simulation, & analysis, along with strong energy policy and market research skills.

Haneea Isaad specializes in energy policy and economics and is currently working as an Energy Finance Analyst at IEEFA. She has been serving as a Technical Advisor on this project for Policy Research Institute for Equitable Development.

Foreword

'Men and nations behave wisely when they have exhausted all other resources,' a politician quipped back in 1967 while commenting on Arab-Israel conflict. As Pakistanis, sadly, we cannot accomplish even that: After having exhausted all other resources, we are still far from acting wisely -- at least in the energy sector.

This lack of wisdom is painfully obvious in how Integrated Generation Capacity Expansion Plan (IGCEP), a government planning document, is prepared and presented. The statistics and outcomes in each of its four iterations since 2019 have varied widely. These variations are as basic as its timeframe. While its first iteration covered more than 20 years (from 2018 to 2040), the latest one has limited itself to just 10 years (from 2022 to 2031). In the same vein, and perhaps more glaringly, some variations concern the very fundamental parameters that determine its outcomes. For instance, while the so-called committed and candidate projects based on hydroelectricity and fossil fuels have all been included irrespective of the fact that many of them are still in the planning phase, the projects based on wind and solar energy have not been given the same treatment. The latest iteration of IGCEP, in fact, has not included even a single project based on wind and solar energy in its projections for 2027.

Independent commentators have also pointed out several other problems in IGCEP. These include, but are not limited to, the absence of an accompanying transmission expansion plan. These commentator rightly observe that any plan to expand energy production is meaningless unless it is supplemented and complemented by a plan to transmit the additional energy to consumers in a failsafe and smooth manner. The current transmission system is neither adequate nor efficient to do so.

These overtly visible failings and flaws of IGCEP-making process prompted us to look into it deeply. Since 2020, Policy Research Institute for Equitable Development (PRIED), Renewables First (RF) and our other partner organizations have engaged extensively with the National Transmission and Despatch Company (NTDC) – simultaneously responsible for the grid operation and the preparation of IGCEP - and the National Electric Power Regulatory Authority (NEPRA) in order to carry out a detailed critique of these plans. But every time we took over findings to these two state entities, we were told that neither did we probe the same questions that NTDC is mandated to address in IGCEPs nor did we deploy the most suitable modeling methodology and that we also ignored the basic assumptions that these plans are premised on.

In order to address these objections, we took a step that no energy sector research institution has taken in Pakistan. In the middle of 2022, we procured PLEXOS, a high end and highly expensive energy modeling software used by NTDC for developing IGCEP. Researchers belonging to both PRIED and Renewables First then worked day and night to collect all the data that goes into the making of an IGCEP. They also delved deep and hard to find out the assumptions that NTDC bases its findings on (though it is another story that not all of these assumptions are fully known yet because some of them remain hidden in the hearts and minds of the authors of IGCEP).

This study has resulted from the hard work of those researchers. Among many other things, it shows how the share of wind and solar power in Pakistan's energy mix can be raised to 47 percent by 2031 even when the latest iteration of IGCEP projects this share to be only 30 percent. By raising this share to the levels forecast in this study, Pakistan can also save as much as 10 billion US dollars over the next ten years mainly through reduced energy imports. This is an opportunity that the perennially cash-strapped Pakistani government must grab with both hands if it is serious in addressing the ongoing energy and economic crises.

That is exactly where the significance and relevance of this study lies: It delineates a clear pathway for reducing Pakistan's dependence on costly and environmentally poisonous fossil fuels and it underscores the heavy financial and climatic costs that we must bear if we fail to make a quick transition away from the old and dirty technologies to new and sustainable ones in our energy sector.

Both PRIED and Renewables First, therefore, expect that the government functionaries working in various parts of the energy sector, researchers, academics, think-tanks, civil society organizations, private entrepreneurs and Pakistan's international development partners take its findings seriously. And not just for discussing them and then discarding them but also to make them an integral part of the policy discourse and policy implementation in the years to come.

Muhammad Badar Alam

Chief Executive Officer

Policy Research Institute for Equitable Development (PRIED)

List of Abreviations

Key Documents

IGCEP	Indicative Generation Capacity Expansion Plan
TSEP	Transmission System Expansion Plan
ISP	Integrated System Plan
ARE Policy 2019	Alternative & Renewable Energy Policy

Institutions & Entities

CCoE	Cabinet Committee on Energy
MoE	Ministry of Energy
NEPRA	National Electric Power Regularity Authority
NTDC	National Transmission Despatch Company
DISCO	Distribution Company (Total 10 in Pakistan)
KE	Karachi Electric
AEDB	Alternative Energy Development Board
IPP	Independent Power Producer
GENCO	Government Owned Generation Company
CPP	Captive Power Plant

Others

VRE	Variable Renewable Energy
kW, MW, GW	Units of Power
kWh, MWh, GWh	Units of Energy
FY	Fiscal Year

Contents

Executive Summary

The electricity needs of Pakistan are growing each year. In the Fiscal Year (FY) 2022, a total of 154 TWh of electricity units (27 GW peak) were consumed in Pakistan. By 2031 this consumption is expected to reach 228 TWh per year (39 GW peak).

To meet the escalating demand for electricity, Pakistan must construct and connect additional power to the national grid. Moreover, the existing power plants pose a financial burden due to their high operational costs, necessitating their displacement with cheaper power sources. The determination of power plants that must be built along with their respective timelines are outlined in the Indicative Generation Capacity Expansion Plan (IGCEP). The IGCEP is a comprehensive planning document prepared annually by the National Transmission Despatch Company (NTDC) and approved by the National Electric Power Regularity Authority (NEPRA).

The latest approved IGCEP specifies that approximately 30 GW of new power plants will be constructed and integrated into the national grid over the next decade. This ambitious endeavor demands a substantial investment, estimated at around USD 40 billion. Effective planning plays a crucial role in ensuring the success of this undertaking and can yield significant benefits.

Towards this end, all the efforts put into the planning and preparation of IGCEP by NTDC are praiseworthy. However, there are several issues with its methodology which include:

- ◊ Incomplete disclosure of power data and under-representation of power costs.
- ◊ Arbitrary constraints put on clean and cheap wind and solar technologies.
- ◊ Classifying entire sets of projects as committed and keeping the modelling tool blind to their capital costs.
- ◊ Separate modeling of NTDC and Karachi Electric (KE) systems lead to the generation of electricity at a higher cost within the KE system.
- ◊ Not exploring the financial implications of delayed or early retirements of expensive thermal power plants

To evaluate the efficacy of the current IGCEP and to explore alternative scenarios for the above stated issues, this study was launched by mutual collaboration of Renewables First (RF) and the Policy Research Institute for Equitable Development (PRIED). For the purpose of this study, we acquired PLEXOS, a state-of-the-art power sector modelling tool, which is also used by the NTDC to optimize addition of new power plants on a least cost principle.

Our team held comprehensive meetings with many power sector experts, agencies, and utility companies. Finally, we fed 300+ power plants into PLEXOS with 4500+ variables and data curves. Over the course of a year, scores of iterations were run and the operation of each plant was carefully reviewed. IGCEP assumptions, data inputs and constraints were replicated and multiple scenarios were analyzed for a 10-year horizon.

Despite having identical assumptions, data and modelling tool as NTDC, our simulations have come up with different capacity optimizations than the ones NTDC is proposing. Some of our major findings are as follows:

1. **A total 18.5 GW of wind and solar capacity must be added to the national grid by 2031 under the least cost principle (34% share of wind and solar technologies in the national grid by 2031)**

Using the same assumptions, data inputs, and constraints as the IGCEP, our model optimized 5.5 GW of wind and solar capacity. This is in addition to more than 13 GW already proposed by the NTDC. In this scenario, nearly 2.5 GW of Hydro power capacity was also selected, which is 1 GW less than the quantum proposed by NTDC. Interestingly, our model did not pick any local coal plant whereas IGCEP inducts 990 MW of local coal in the KE system.

2. **If the committed projects are evaluated and revised on merit, nearly USD 8.6 billion can be saved by replacing some of them with cheaper wind and solar energy technologies (37% share of wind and solar technologies in the national grid by 2031)**

Committed projects are plants that have not been built or entered commercial operation to date, yet their feasibility is not evaluated by the IGCEP. In this scenario we fed both the initial capital expenditure (CAPEX) and ongoing operational expenditure (OPEX) of these projects into PLEXOS and allowed it to select, reject or optimize them. Our model ended up selecting only about 8 GW out of a total 14 GW of these projects. This is a 43% reduction in their capacity which the model replaces with cheaper RE projects, resulting in a further addition of 3.5 GW of wind and solar capacity. Notably, the replacement of these expensive committed projects, which were predominantly thermal or hydro-based, with wind and solar technologies resulted in total cost savings of USD 8.6 billion for the power sector.

3. **By removing the arbitrary constraints put on solar and wind energy in the IGCEP, nearly USD 10 billion can be saved in the first 10 years, and USD 180 million saved each year afterward in fuel savings. (47% share of wind and solar technologies in the national grid by 2031)**

IGCEP imposes some arbitrary and unexplained constraints on candidate RE projects that lead to a lower share of wind and solar technologies in the national grid. When these constraints, apart from the 2-year lead time, were removed, a further addition of 11 GW of wind and solar capacity was recommended by the model. This demonstrates a least cost potential of a total of 39 GW (equivalent to a 47% share of RE) in the national grid by 2031. The total cost savings expected in the 10-year horizon for this scenario are nearly USD 10 billion, which however will also continue to result in massive savings in fuel costs after the 10 years period, nearly USD 180 million each year.

4. **If we connect the KE system with the rest of the country on a central dispatch basis and ensure electricity supply, we can save an extra $2.2 billion in the next 10 years.**

Currently, the power sector of Pakistan is divided into two segments: the NTDC region and the KE region. The cost of electricity is significantly cheaper in the NTDC system which is nearly 12 times larger in terms of capacity. These two systems are connected by a tie-line through which a maximum of 1100 MW of electricity can flow from NTDC to KE. Although KE has invested in building larger tie-lines recently, greater supply of electricity from NTDC to KE remains unavailable due to non-willingness of the former.

In this scenario, we modeled the two systems and allowed a free flow of electricity between the two systems. This led to a 46% reduction (48 TWh over 10 years) of electricity produced in the KE region.* Moreover, our results showed that as a result of this displacement of electricity generation from KE to NTDC, savings of nearly USD 2.2 billion can be achieved in the next 10 years, while USD 580 million each year can be saved each year beyond the 10-year period.

5. **If we can find a solution for the contractual off-take obligations of just 9 out of 150 power plants in Pakistan's electricity mix, we can save up to $12 billion in the next 10 years**

In the power sector of Pakistan, there are a total of nine thermal power plants (three in NTDC and three in KE, constituting a total of 5776 MW) that have been guaranteed minimum power offtakes between 50-75% due to fuel contracts and supply constraints. When we removed these obligations, PLEXOS displaced 65% (214 TWh) of their electricity output to cheaper sources, resulting in total cost savings of USD 12 billion over the next 10 years. While we acknowledge that the minimum contractual obligations of thermal power plants cannot simply be removed, the astounding cost of these obligations must nevertheless urge us to reflect on our careless planning practices and repetition of past mistakes.

The above results are a keen reminder of how important planning is and how far reaching its consequences can be. Without a transparent and well-designed power sector plan that is subject to public scrutiny, Pakistan faces the risk of constructing expensive and inefficient power plants worth billions of dollars. The

* While IGCEP 2022-31 increases the capacity of tie-line from 1100 MW to 2050 MW in FY 2025, this is no longer the case in actual fact. The commitment to increase the capacity of tie-line has since been foregone, as we have been told by KE officials. Therefore, for the central dispatch scenario, we have chosen to compare our results with the business as usual case of tie-line fixed at 1100 MW throughout the horizon.

burden of these careless decisions will inevitably fall on the shoulders of the people of Pakistan, who will be bound to pay these costs for years to come. The lack of transparency in the power planning process results not only in expensive fuel prices for electricity generation but also contributes to the ongoing problem of circular debt, which continues to escalate.

For decades now, power plants have been built without proper planning. While NTDC was mandated by the grid code to come up with a generation plan back in 2005, it failed to do so for 15 years. As a result, Pakistan is now burdened with costly plants and commitments which people are struggling to pay for. In 2022 alone, Pakistanis paid PKR 41 billion for partial load adjustment charges resulting from the underutilization of thermal power plants (with only 46% utilization) and PKR 721 billion in capacity payments.

There is also little focus on upgrading our outdated and fragile transmission and distribution systems and reducing their losses. We still do not have a transmission plan in place. The transmission losses in the FY 2022 amounted to a staggering PKR 520 billion. The power sector of Pakistan is bleeding money, which is alarming for a country with already piled-up debts and depleting reserves. We can hardly afford such negligence.

Our results recommend that a lot more wind and solar energy technologies must be added to the national grid in a systematic manner over the next decade, with special emphasis on small-scale and local investment alongside modular approaches to local manufacturing to ensure the strengthening of local markets. Wind and solar energy must be added to the national grid not only because it is green, but because it is by far the cheapest. It is also more reliable compared to electricity from imported fuels which are constantly subjected to global fluctuations.

Our planning committees also must realize that planning Pakistan's energy system can no longer be done in silos, planning electricity generation and transmission separately from fuel sources such as gas or energy demand sectors such as water supply. Instead, we require a comprehensive approach that studies our energy system as an integrated, co-dependent system. The cost and availability of one resource directly impacts the rest of the energy ecosystem's demand for availability. As new technologies are commercialized and introduced to the grid (i.e. electric vehicles, battery and hydrogen storage), we must learn and understand their impact by looking at the system holistically as a single unified energy system.

The power sector of Pakistan: An overview

The power sector of Pakistan is a highly centralized and regulated system and can be divided into three separate sections: generation, transmission, and distribution.

The only exception is K-Electric (KE), which is a vertically integrated utility and carries out all three main functions of generation, transmission, and distribution within a 6500 km^2 territory including Karachi and its adjoining areas.

Generation of electricity across the country is carried out by a combination of state-owned Generation Companies (GENCOs), nuclear plants and Independent Power Producers (IPPs), with the Water and Power Development Authority (WAPDA) responsible for major hydropower development.

Transmission of electric power across the country is the responsibility of NTDC which operates the primary transmission network of Pakistan supplies electricity to all areas of the country except the zone of KE. KE being a privately owned and vertically integrated utility possess its own transmission system, which is the sole network for transmitting power to Karachi and some surrounding regions. Transmission between the NTDC and the KE system can only occur through an 1100 MW tie-line, which KE uses to import a limited quantum of cheaper electricity from NTDC each year.

Distribution is carried out through ten publicly owned Distribution Companies (DISCOs). These are responsible for electric power distribution in their respective areas.

The regulation of the power sector is carried out by NEPRA which includes provision of licenses and oversight for all entities operating in the generation, transmission, and distribution sectors. Long-term planning for generation and grid expansion is carried out by the NTDC. Decisions of the government are exercised through the Ministry of Energy and the Cabinet Committee on Energy (CCoE).

37,949 MW NTDC's Installed Capacity **Solar and Wind 6%** **Hydro 26%** **Thermal 66%**	**3,319 MW** KE's Installed Capacity **Renewables 3%** **Thermal 97%**	**26,945 MW** Peak demand of Country **36.6 Million** No.of Electricity Consumers
143,017 Gwh NTDC's Generation Fleet FY 2022	**10,861 Gwh** KE's Generation Fleet FY 2022	**20 - 25%** Transmission and Distribution Losses

Overseeing Bodies

Federal

MOE (Ministry of Energy)

CCOE (Cabinet Committee on Energy)

Mediator

CCI (Council of Common Interests)

Provincial

Provincial Energy Departments

NEPRA (System Regulator)

NTDC (System Planner and Operator)

Generation

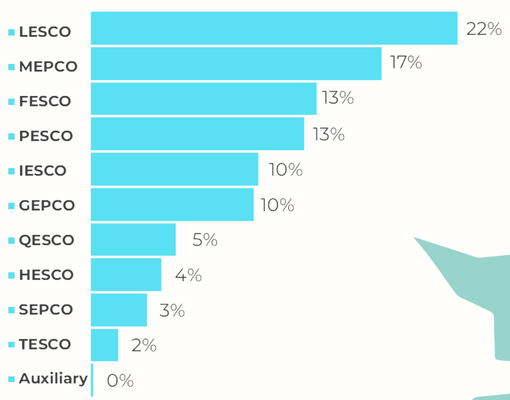
56 Fossil Fuel Plants
6 Nuclear Plants
19 Hydel Plants
11 Small Hydel (<30 MW)
7 Solar Plants
36 Wind Plants
9 Bagasse Plants

Transmission (NTDC)

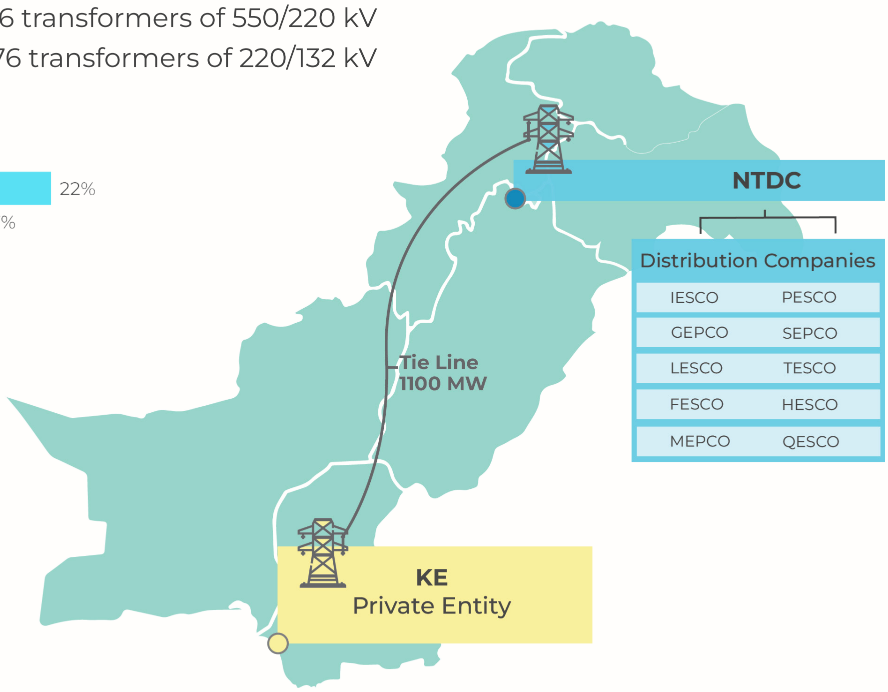
Lines
8,388 km of 500 kV (76 circuits)
11,611 km of 220 kV (163 circuits)
Grid Stations
17 grid stations of 500 kV
50 grid stations of 220 kV
Transformers
46 transformers of 550/220 kV
176 transformers of 220/132 kV

Distribution

30,520 km of 132 kV lines
907 Grid Stations of 132 kV
2219 Power Transformers
55871 Distribution Transformers
353903 Feeders of 11 kV



Share of electricity consumption - FY 2022



In Pakistan, a two island approach is followed in which the power sector is split into two subsystems: NTDC and KE. Both sectors manage their own supply and demand which results in more expensive dispatch in the KE system. This approach also fails to benefit from demand-curve superposition.

Central Dispatch - An Alternative Approach

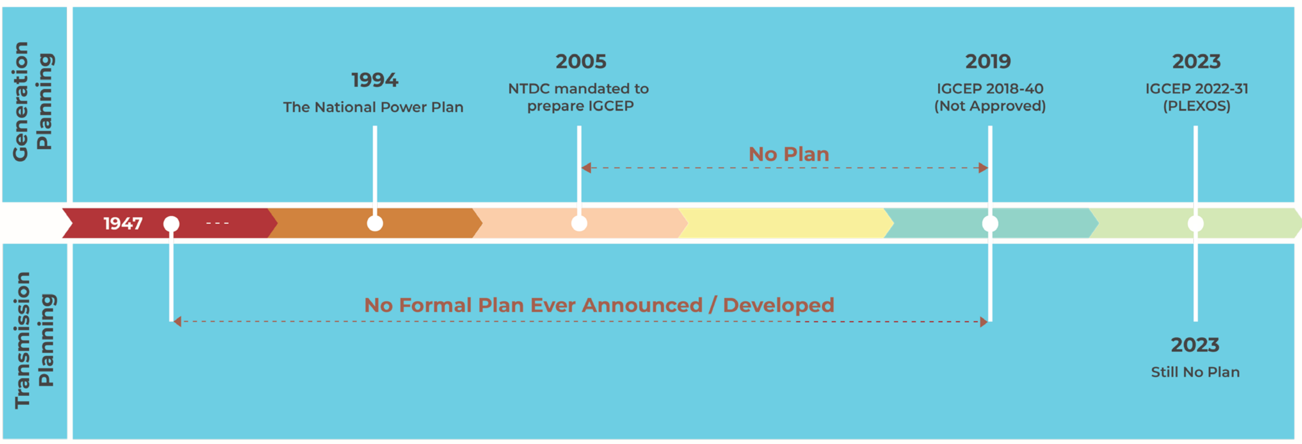
When the whole power system is managed/operated by a single entity (i.e. System Operator), it is called a central dispatch approach. This approach aims to minimize the system production cost by determining the optimal dispatch instructions for all generators in the system based on prices and technical parameters provided by the participating parties.

How does power planning take place in Pakistan?

The planning process in the power sector can be categorized into two major categories: generation planning (laid out in the IGCEP) and transmission planning (laid out in the TSEP). The IGCEP is a yearly document which is prepared and approved by the regulator each year whereas the Transmission System Expansion Plan (TSEP) may be prepared for one, three, five, or 10 years. The first IGCEP in the history of Pakistan was approved in 2021 whereas no TSEP to date has been prepared. According to policy, the IGCEP and the TSEP are meant to collectively lay out the viability of any generation project.

In the early decades of post-independence of Pakistan, greater emphasis was placed on water resources management rather than addressing energy concerns. The establishment of WAPDA in 1958 was also primarily for managing water resources to boost the country's agricultural economy. Although various studies on power system planning were later conducted to support the government's regular five-year medium-term plans, no energy policy was formally announced until 1994. It was only in 2005 that NTDC was mandated by the grid code to develop a comprehensive capacity expansion plan called the IGCEP. NTDC failed to produce any such plan in the next 15 years. Power plants continued to be built arbitrarily, resulting in the disastrous economic conditions which Pakistan is experiencing today.

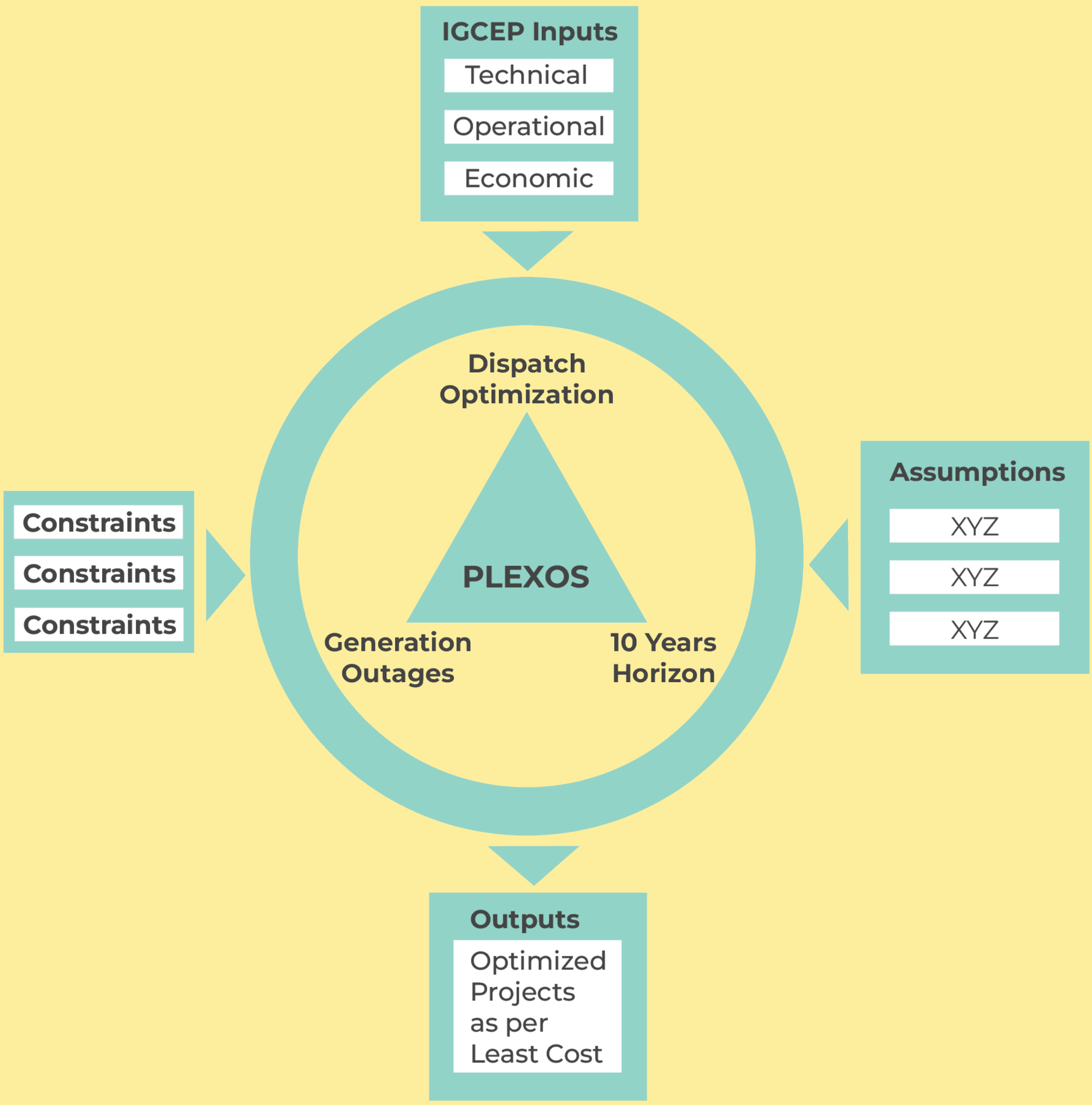
When NTDC's first plans were submitted to NEPRA in 2019 and 2020, they were inadequate and of poor quality, leading to their rejection. It was only when in 2021, the World Bank made the disbursement of a $400 million loan contingent on the approval of IGCEP, it was hastily approved by the regulator. However, the subsequent plan, which was due in the June of following year, came more than three months late. Such institutional failures and arbitrary delays are common in the power sector of Pakistan and result in serious consequences for the people. While the grid code also required NTDC to submit the TSEP along with the IGCEP, no TSEP has been prepared or submitted to date.



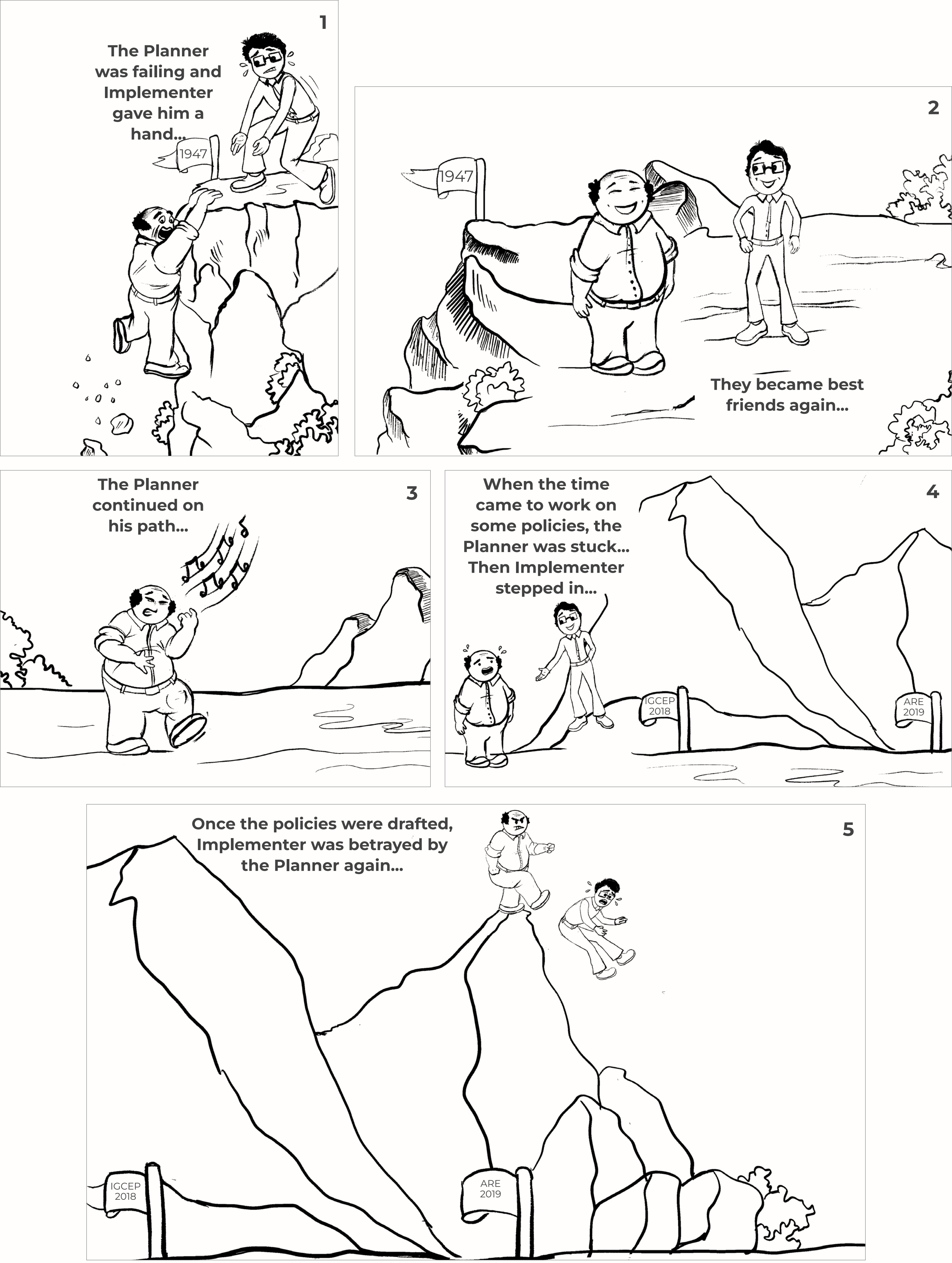
The IGCEP is prepared by the NTDC each year by carrying out a least cost modelling exercise for all possible generation options for a 10 year horizon in a software called PLEXOS. This process involves a number of assumptions, constraints, and data inputs.

Some Notable Assumptions Involved in IGCEP 2022-31

- Capital costs of projects which have been declared committed will not be entered into the model or reported
- For candidate local coal, the fixed fuel cost component will be 11.2 $/Ton (71.821 $/kW-year) and fuel price will be 9.97 $/Ton (0.88 $/GJ). These prices are much lower than the ones reported in the Pakistan Electricity Outlook of 2022.
- There will be a 4 year lead time for candidate local coal projects and a 2 year lead time for wind and solar technologies.
- Only 500 MW of wind can be added in 2024 and 2025 each. Only 3,120 MWp of solar can be added 2024 and only 1,300 MWp yearly from 2025 onwards. 370 MW of Net Metering Capacity will be added to the national grid from 2022 onwards.




P
I
Planner and Implementer are best friends
Plan
Coal
Power Plant
Plan
Coal
Power Plant
....and one fine day, the Planner parted ways, leaving
Implementer behind....


1
The Planner was failing and Implementer gave him a hand...
1947
2
1947
They became best friends again...
3
The Planner continued on his path...
4
When the time came to work on some policies, the Planner was stuck... Then Implementer stepped in...
IGCEP 2018
ARE 2019
5
Once the policies were drafted, Implementer was betrayed by the Planner again...
IGCEP 2018
ARE 2019

Do renewables lower the average generation cost of the electricity mix?

1

What the policy says

"Expensive electricity of thermal plants shall be displaced by AREPs wherever such displacement allows a lowering of the average system generation cost, as determined by the IGCEP outputs"

- ARE Policy Clause 1.4.4

2

What the costs indicate

RE costs have declined sharply over the past 10 years with nearly 75% reduction seen in the tariffs awarded by NEPRA to both utility scale Solar PV and wind.

3

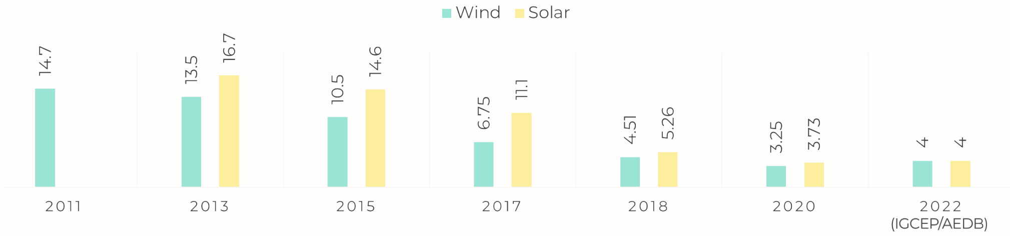
What the experts are recommending

"Least cost electricity in Pakistan requires a rapid expansion in VRE Capacity"

– World Bank

"Much higher shares of VRE are recommended for Pakistan than those presented in IGCEP"

- Agora Energiewende



Levelized Tariff Trend for RE in Pakistan (US Cents/kWh)

Even though solar and wind technologies today are already the cheapest (4¢ per kWh as per AEDB & IGCEP), asking whether they can lower the average generation cost of national electricity grid is a separate question. This is because due to their variable nature, wind and solar technologies require some amount of **balancing** by other generation sources. Moreover, the national grid is also locked into large amounts of **stranded costs** in the form of capacity payments, minimum off-take requirements and commitments towards projects in their advanced stages of construction.

The **goal of this study** is, therefore, to demonstrate whether adding large amounts of VRE in the national grid can still lower the "average system generation cost" while all other costs due to balancing, capacity payments and penalties for thermal related generation are continued to be paid.

To build synergies, experts from RF and PRIED teamed up to decipher the power planning process, model the power sector, and to understand and highlight the existing gaps. In IGCEP 2021, the targets for solar and wind were revised down to 10% in violation of the ARE Policy 2019. Further, RE definition was expanded to include Hydro, which further diluted the ARE policy goals. The economics of solar and wind instead advocated for a higher share in the power mix. Our study was initially motivated by these factors. While the 2022 iteration of IGCEP raised the share of wind and solar technologies to 30% by 2031, we continued to feel the need for an assessment of true cost competitiveness of VRE in the national grid under business as usual case as well as some additional scenarios.

Where We Stand Today - 2023

4.2% Wind

1.2% Solar

Where we must be headed - 2030/31

Nationally Determined Contributions (NDCs)

60% energy production from RE

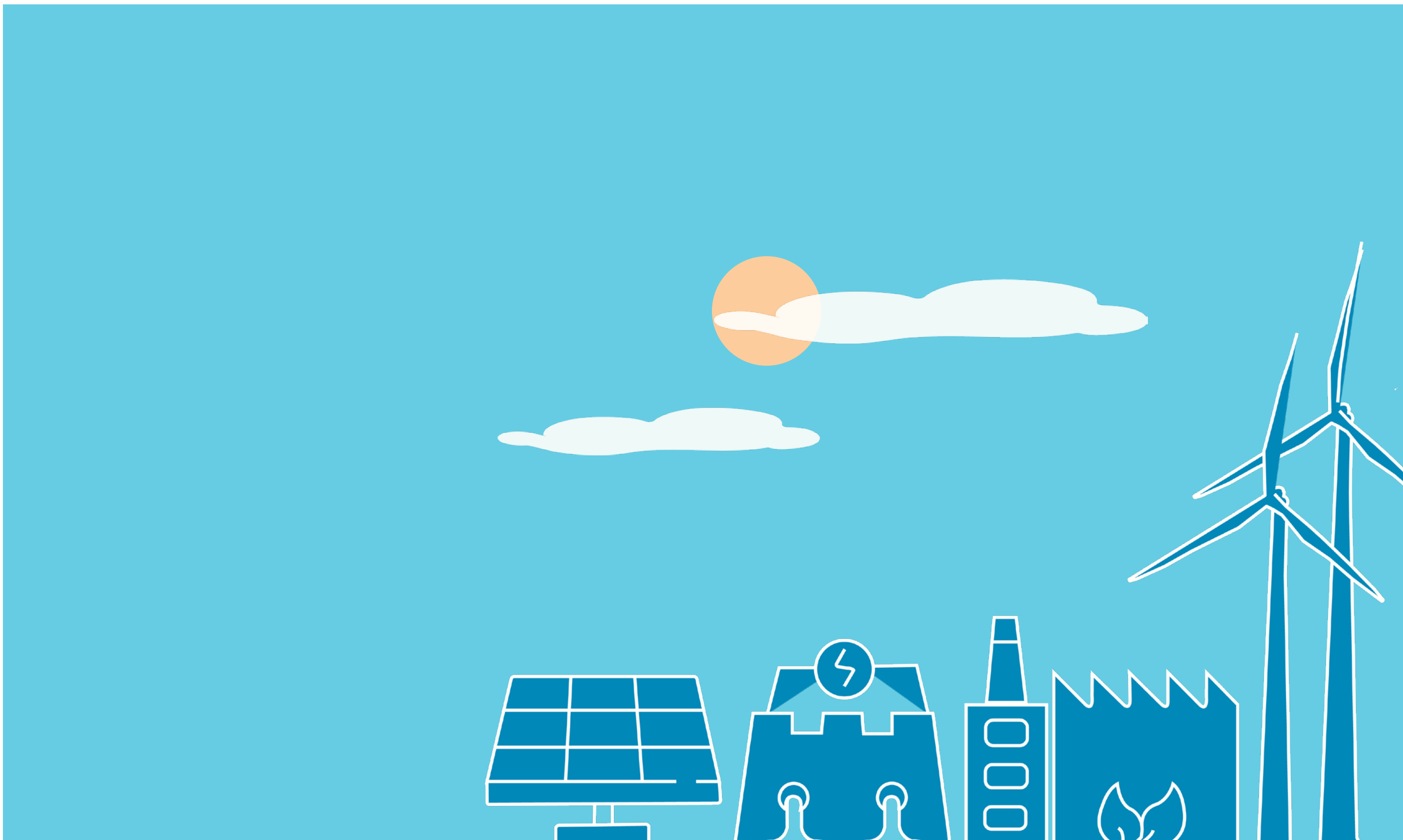
ARE Policy 2019

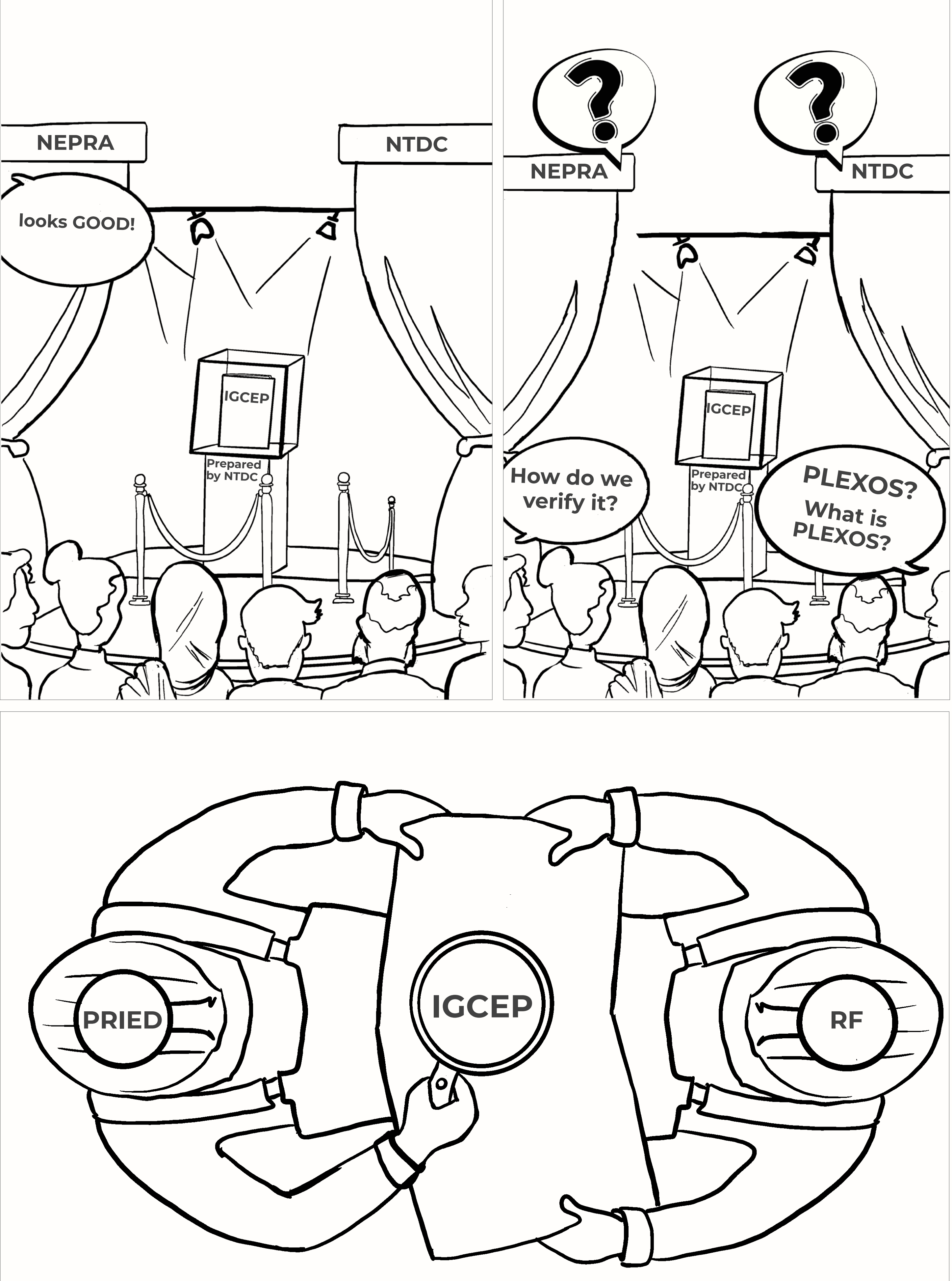
30% Share of Wind and Solar in National Electricity Mix by 2030 – ARE Policy

IGCEP 2022-31

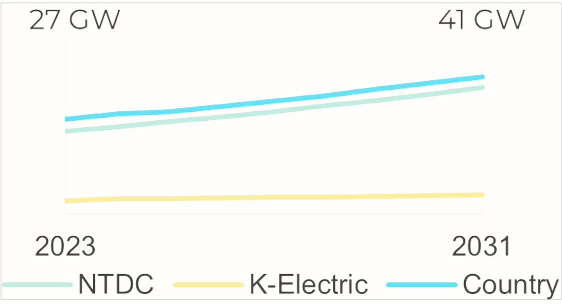
30% Share of Wind and Solar in National Electricity Mix by 2031

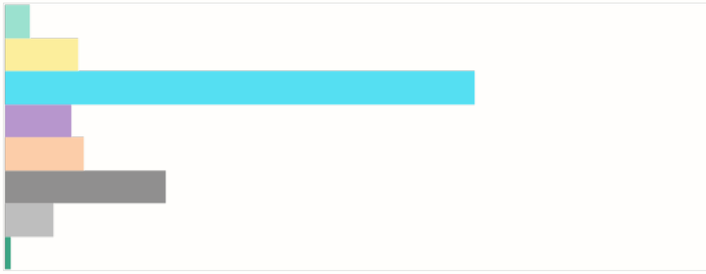
A higher share of solar and wind is indispensable for sustainable development in Pakistan. The results of existing studies, declining costs of solar and wind technologies, unforgiving impacts of climate change (2022 floods), and external energy supply shocks, all factors emphasize an indigenous green energy transition.




NEPRA
NTDC
looks GOOD!
IGCEP
Prepared by NTDC
NEPRA
NTDC
IGCEP
Prepared by NTDC
How do we verify it?
PLEXOS? What is PLEXOS?
PRIED
IGCEP
RF

What does the RF-PRIED PLEXOS modelling process look like?



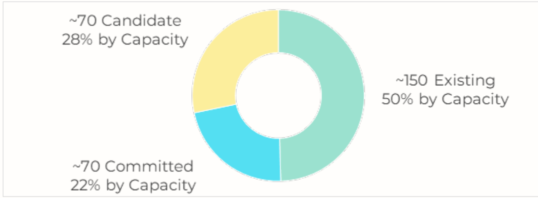


Load Forecast

The forecasting exercise for maximum energy and power is conducted by considering the projected GDP growth (4.3% in this case) over a 10-year period. We utilized the same projections as IGCEP 2022-31 for this analysis.

Feeding 300+ Generation Options

Technical data from existing, committed, and candidate power plants, including capacity, minimum stable level, heat rate, ramping capability, and outage allowance, is fed into PLEXOS for analysis.

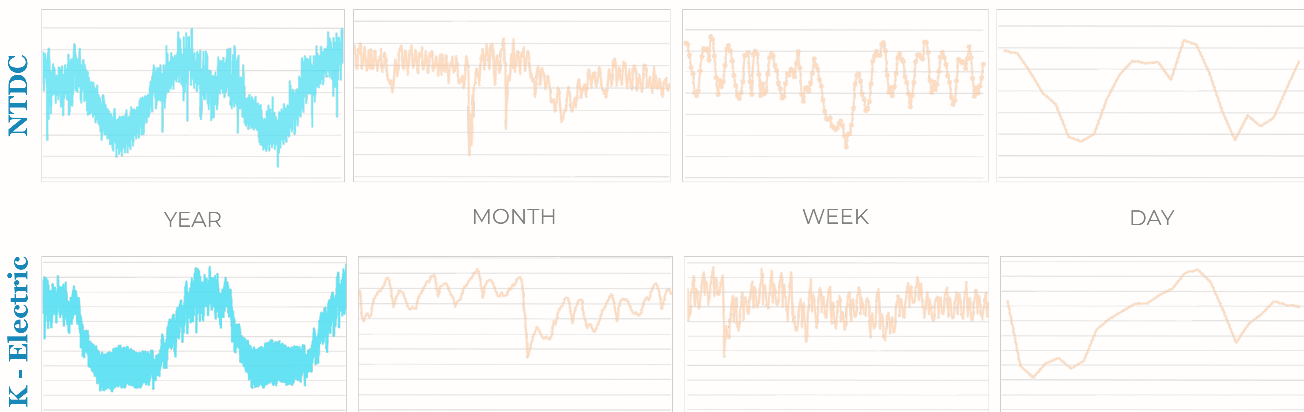


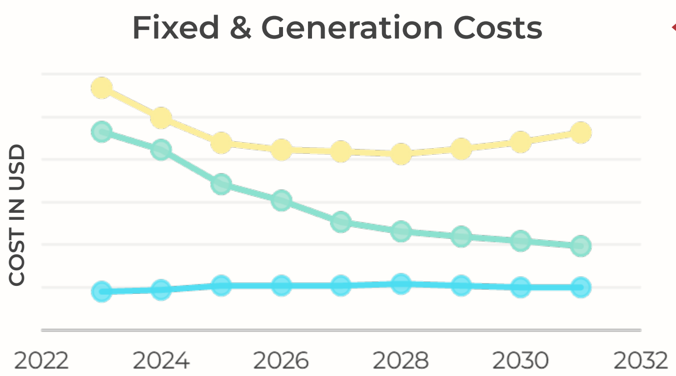
Economic & Financial Parameters

Power plants have varying build costs, capacity payments, and maintenance costs (fixed and variable). Additionally, the economic life of each plant differs, with cost recovery typically expected over 50+ years for hydro and nuclear plants, and 30 years for other technologies. Fuel costs also vary by plant and are adjusted for successive fiscal years based on the EIA Annual Electricity Outlook 2022 projections.

Hourly Load Profiles

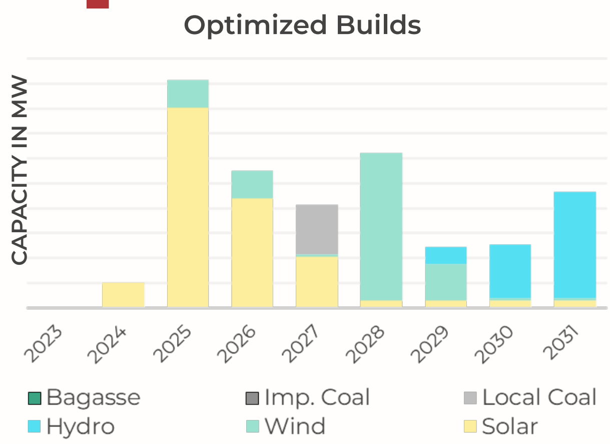
Hourly demand profiles play a crucial role in accurately assessing wind and solar intermittency. In the initial models, these profiles were generated using specific algorithms based on typical day profiles. However, later on, NTDC provided exact hourly profiles for 175.2k hours, significantly enhancing the reliability of the model.





Contractual Obligations & Constraints

Each power plant and technology may be subject to various constraints and obligations such as minimum energy offtake requirements, must run statuses, and retirements. These details are entered in line with IGCEP data.



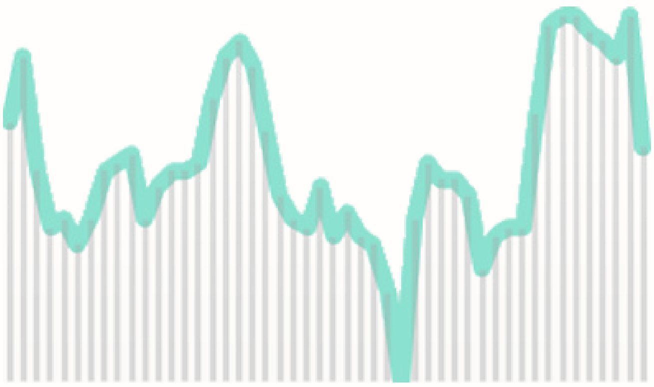
Projects Selected by PLEXOS

Taking into consideration all respective constraints, builds, dispatch capability, and financial parameters, PLEXOS recommends technology builds on a least-cost principle, year by year. This includes detailed data on costs (fixed and generation) and hourly dispatch for each plant in the system.

Wind & Solar Profiles

Hourly solar and wind data were fed into the model for 8,760 hours of the year. Separate data is entered for utility-scale, distributed generation, net metering, and existing plants.

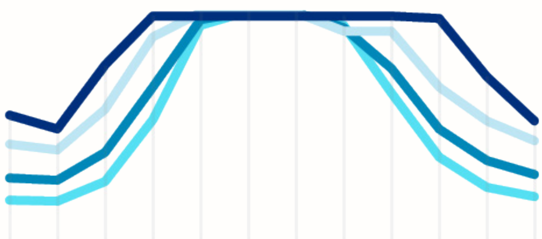
Typical Solar Day



Typical Wind Day

Hydro Profiles

Generation from hydropower plants fluctuates according to water flow patterns, with peak typically occurring during the summer. Profiles for maximum monthly generation and peak power output, as well as yearly constraints, have been inputted.



Typical Hydro Year

Gathering power sector data is rife with challenges in Pakistan

Planning is important for the growth of any sector and easy access to data and transparency are crucial to good planning. Transparency in data not only leads to better accountability but also allows third-party researchers to verify and substantiate public sector plans.

In the energy sector of Pakistan, there is a major challenge involved in availability and transparency of data. While some information is available through the State of Industry Reports, Tariff Determinations, and Generation Licenses, its extraction remains a laborious task. Many documents are provided in the form of old images and non-copiable formats. There is plenty of missing and inconsistent information. Is provision and accessibility of data sufficient in Pakistan? The answer is No!

Data transparency is key to public sector advancement and results in a number of benefits:

- Ensures efficiency & accountability
- Leads to value and knowledge creation; boosts innovation
- Improves stakeholder participation
- Improves quality of data and related services over time

The success of power sector modeling largely depends on how accurately the model captures the complex and rapidly changing ground conditions.

In our project, which has spanned over a year, data collection has been a major challenge. The more our team delved into it, the more cumbersome it became.

Nuclear Data – Did you know!

Did you know that the tariff determinations of nuclear power plants are not available on the NEPRA website? Even the Pakistan Atomic Energy Commission (PAEC) provides only limited technical specifications. Despite claims being made about nuclear power being a reliable and affordable source of abundant power, the truth remains concealed. Much of the costs associated with nuclear power generation remain shrouded in mystery due to the non-availability of data.

Absent Hydropower Data!

Hydropower data is almost absent. While basic project details such as location, generation capacity, hydel potential, and type of hydropower, are usually available. But seasonal hydel patterns which are essential to create generation profiles are not available. To fill this data gap, our team geographically mapped committed and candidate hydropower projects traced their river streams to existing hydropower projects where possible, and then searched for their annual river flows. The annual river flows were available for a few plants but in different documents such as Environmental Impact Assessments (EIA) and Technical Studies.

Our data requirements were extensive since we aimed to model the entire power generation sector. Our team initially gathered publicly available data, meticulously examining their inconsistencies and identifying gaps. To fulfill our additional needs, we collaborated with multiple public and private entities through Non-Disclosure Agreements (NDA). We appreciate the support of LUMS Energy Institute in this endeavor who continued to support us in our knowledge and data-related needs from time to time.

We strongly emphasize the importance of prioritizing data transparency to enhance the national planning processes and promote the active participation of interested stakeholders, enabling them to make contribution for the benefit of the overall system.

It is necessary to have open access to comprehensive planning data in workable formats of all generation technologies (including nuclear plants, and hydropower plants). This access is essential to establish the reliability of the generation planning process. The need for a centralized, one-stop data portal is critical and requires immediate attention.

Power sector data must be made accessible and transparent.

Pakistan's tax-paying citizens have a right to know where their hard-earned money is being spent!

Data Collection Challenges
Inadequacy of publicly available data
Non-copiable data formats
Lags in data provision
Unavailability of specific parameters of power plants' data
Uncooperative behavior of entities on data requests
Inconsistency in data

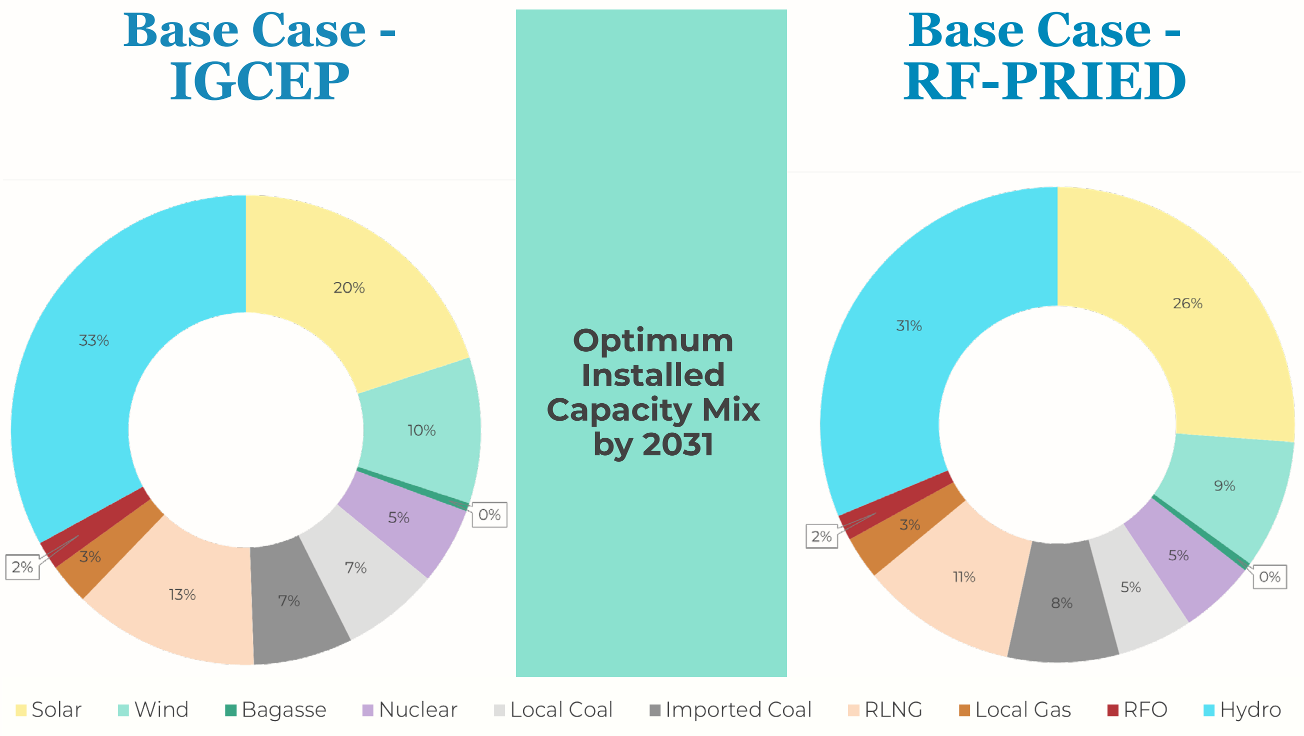
The mystery of capacity payments

Did you know that the mechanism for calculating capacity payments is missing from tariff determinations? Instead, this information is typically part of Power Purchase Agreement (PPA) annexures, which are not accessible to public.

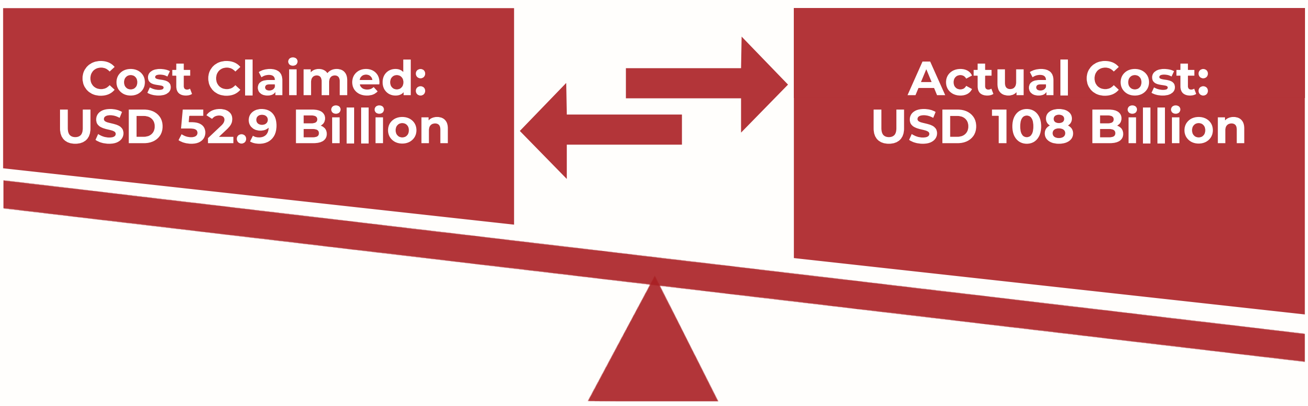
What are ramp rates?

Ramp rates are the speed with which power plants can increase or decrease their electricity production. When the demand in the system changes, plants must be ramped up or down. The rate and costs of ramping a plant up and down vary significantly across technologies.

Comparison of findings with NTDC's plan, the IGCEP 2022-31



30% (<21 GW)	**2031** Share of Wind and Solar	35% (24 GW)
69.3 GW	Total Installed Capacity	70 GW



The marked difference between costs arises from the omission of various costs by NTDC, deemed irrelevant for optimization, such as capacity payments and CAPEX of committed projects. However, these omissions provide a misleading picture of the total projected costs that the power sector of Pakistan is expected to incur in the next 10 years.

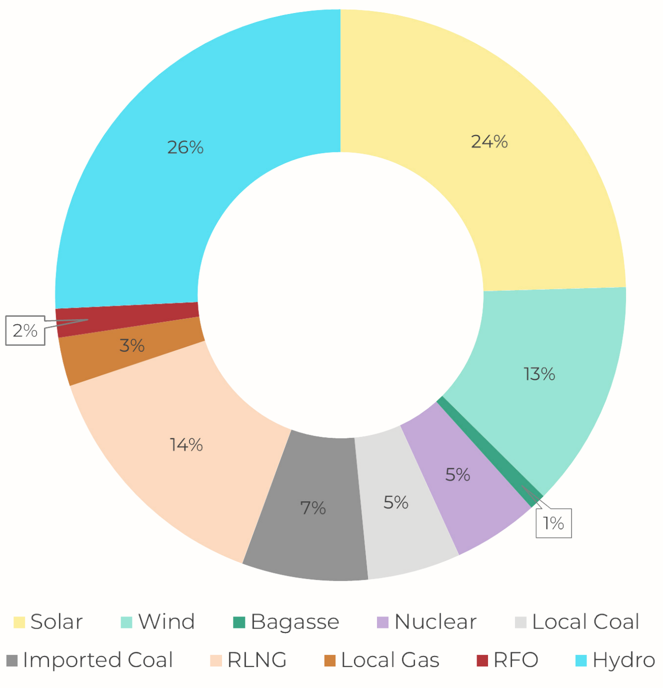
Pakistan can benefit from massive savings in the power sector through a combination of Renewables and minor changes

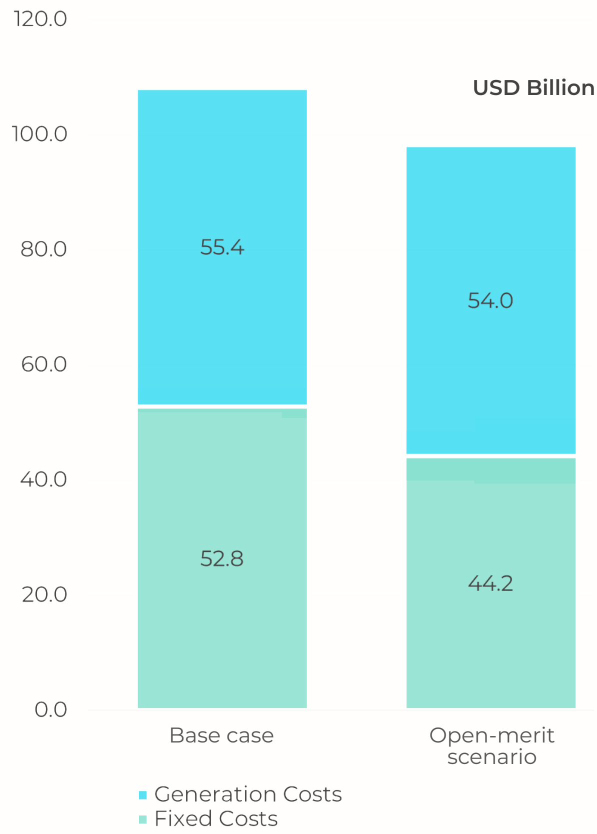
If committed projects are revised on merit, constraints on RE are removed and timely auctions are conducted, the total share of affordable wind and solar technologies can be raised to 47% (39 GW) consistent with the clause 1.4.4 of ARE policy 2019

Did you know!

Over 43% of committed projects are not deemed cost optimal by PLEXOS.

Optimum Installed Capacity Mix for 2031 – Recommended by PLEXOS in an open merit scenario





On the other hand, financial repercussions of not following through with ARE targets are dire!

If the combined share of wind and solar capacity is limited to 10% in the national grid by 2031 and additional load is shifted to new hydro

Wind & Solar (<10%)
Hydro (~36%)

$2.5 billion lost in first 10 years

$535 million lost in each subsequent year

If the combined share of wind and solar capacity is limited to 10% in the national grid by 2031 and additional load is NOT shifted to new hydro

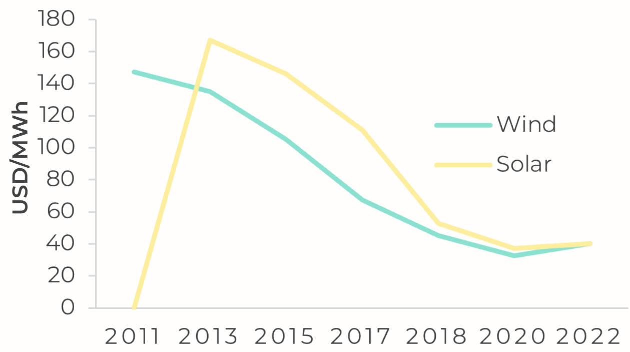
Wind & Solar (<10%)
Hydro (<27%)

$3.1 billion lost in first 10 years

$980 million lost in each subsequent year

How much do wind and solar technologies really cost?

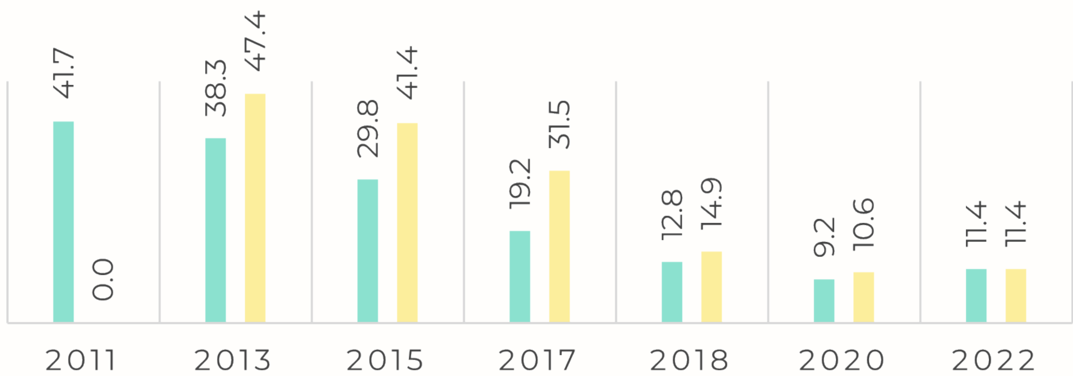
The IGCEP 2022-31 estimates the generation cost from wind and solar technologies at 4¢ per kWh on the suggestion of AEDB. However, our team created an independent LCOE model to ascertain this cost based on data available from past tariff determinations of solar and wind technologies available on NEPRA's website.



Tariffs awarded to wind and solar projects in last 10 years
Source: NEPRA, Pakistan

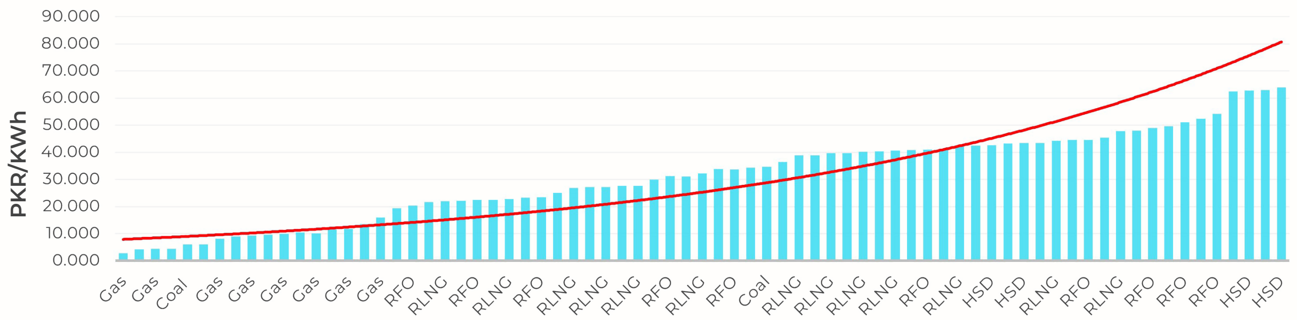
Average tariffs awarded to wind and solar projects in auction globally
Source: EIA, Global

Renewable Energy has become the cheapest source of electricity globally, now competing with coal which has historically been the cheapest source of power generation. Over the past decade, the market for renewables has seen a sharp drop in prices. The above figures show the trend and comparison for solar and wind technologies taken from Global Average Auction Prices as provided by EIA and Tariff Determination of NEPRA.



Cost of wind and solar in Pakistan (Tariff determinations by NEPRA in PKR, indexed at 285 PKR/USD)

In many ways, this is an unfair comparison for wind and solar which are cleaner technologies and have lower negative environmental and social impacts. Moreover, the costs of wind and solar represented here are indicative of levelized costs (mostly CAPEX) whereas the cost of thermal only indicates the marginal cost of electricity (excluding both CAPEX and fixed fuel costs). Even with such a disproportionate comparison, the cost of electricity from solar and wind is still lower.



Cost of thermal generator in Pakistan for various thermal tecnologies as per April 2023 Economic Merit Order

SCENARIOS

Base Case

The base case scenario of our model was developed using identical assumptions, constraints and data inputs as the IGCEP 2022-31. However, our model recommended an additional 5.5 GW of wind and solar capacity in the total mix, supplementing NTDC's proposal of 13 GW. These additions point towards a 34% share of wind and solar technologies in the national power capacity mix by 2031. Additionally, the model also optimized approximately 2.5 GW of hydropower, which is 1 GW less than the capacity proposed by the NTDC. Notably, while the IGCEP also recommended an induction of 990 MW of local coal capacity in the KE system, according to our model this is not financially feasible.

Optimum Capacity Addition and Investment Required

New Capacity Built: 39 GW
Total Investment Required: $40 Billion

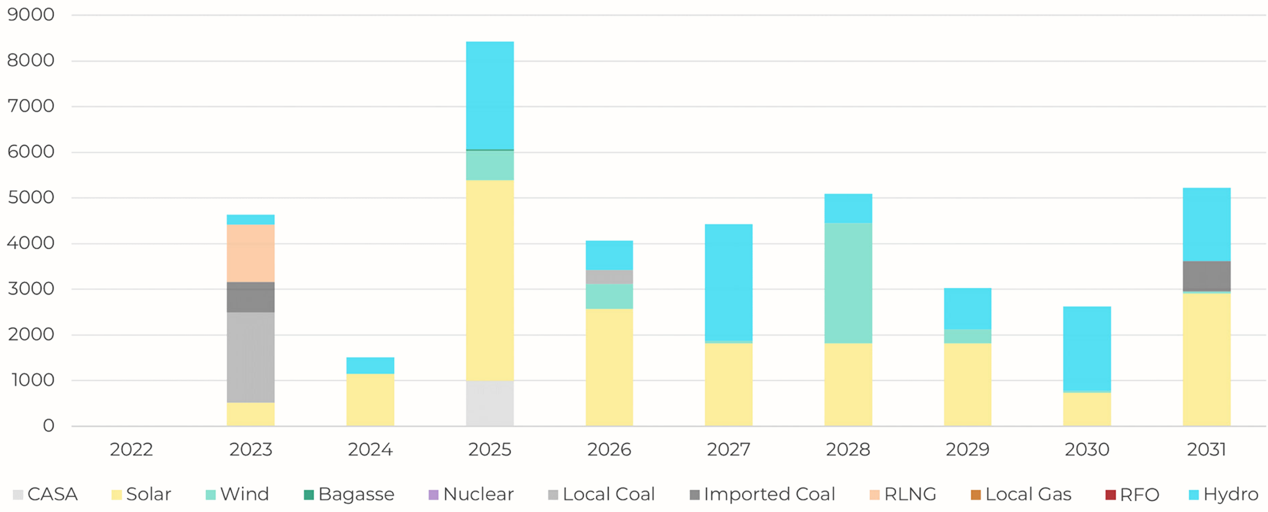
17.7 GW
$9 Billion

4.2 GW
$5 Billion

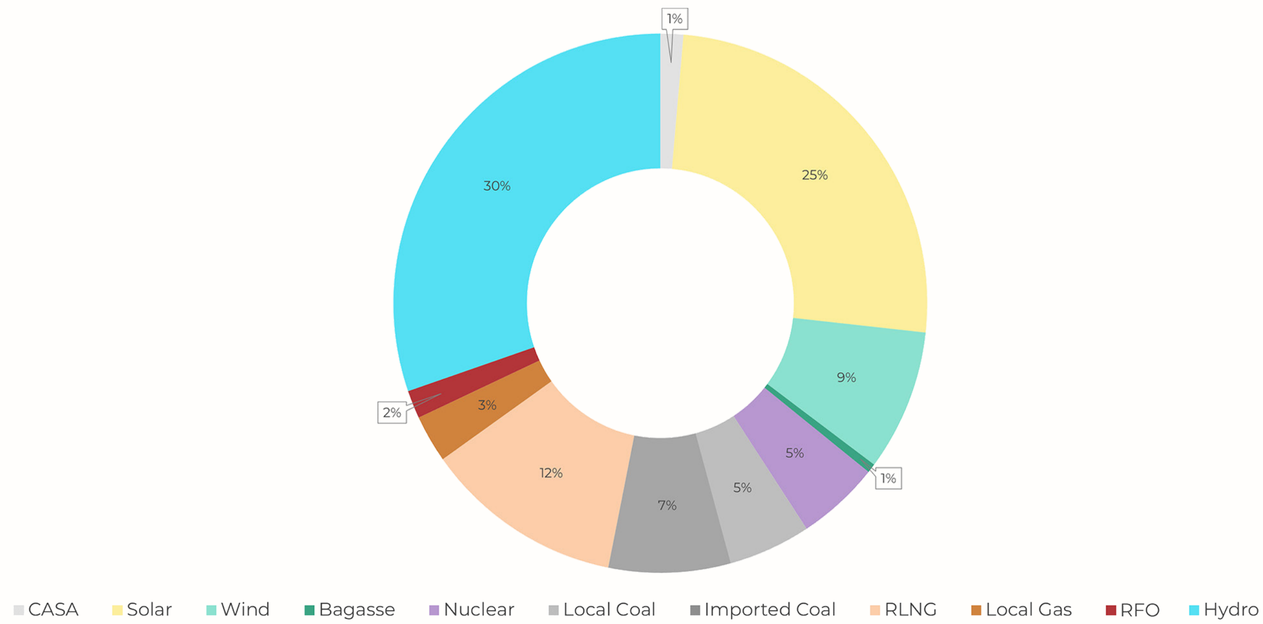
11.1 GW
$21 Billion

Candidate Projects (MW)												
Fiscal Year	Hydro	Imported Coal	Local Coal	RLNG	Nuclear	Bagasse	Solar PV	Wind	KE Local Coal	KE Solar PV	KE Wind	Capacity Addition/Year
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	10	0	0	0	0	0	500	0	0	0	0	510
2025	5	0	0	0	0	0	3870	500	0	150	50	4575
2026	8	0	0	0	0	0	2050	500	0	150	50	2758
2027	0	0	0	0	0	0	1300	0	0	150	50	1500
2028	99	0	0	0	0	0	1300	2578	0	150	50	4177
2029	550	0	0	0	0	0	1300	257	0	150	50	2307
2030	1490	0	0	0	0	0	214	0	0	150	50	1904
2031	484	660	0	0	0	0	2386	1	0	150	50	3731
Total	2646	660	0	0	0	0	12920	3836	0	1050	350	21462

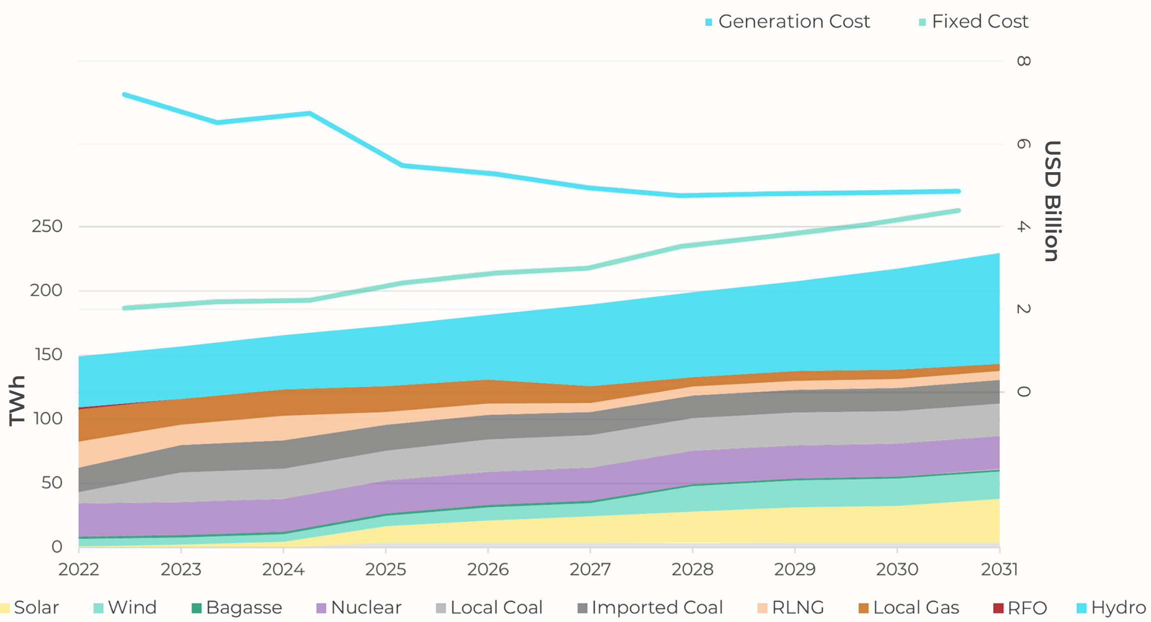
Committed Projects (MW)										
Fiscal Year	CASA Import	Local Coal	RLNG	Hydro	Bagasse	Solar PV	Imported Coal	Net Metered Solar	Wind	Capacity Addition/Year
2022	0	0	0	20	0	0	0	0	0	20
2023	0	1980	1263	217	0	150	660	370	0	4640
2024	0	0	0	342	0	282	0	370	6	1000
2025	1000	0	0	2355	32	0	0	370	94	3851
2026	0	300	0	641	0	0	0	370	0	1311
2027	0	0	0	2558	0	0	0	370	0	2928
2028	0	0	0	545	0	0	0	370	0	915
2029	0	0	0	350	0	0	0	370	0	720
2030	0	0	0	350	0	0	0	370	0	720
2031	0	0	0	1124	0	0	0	370	0	1494
Total	1000	2280	1263	8502	32	432	660	3330	100	17599



Yearly Capacity Additions to the National grid (MW)



Capacity Mix - 2031



Generation Mix Projections - Base Case

Treating Committed Projects as Candidate

The PLEXOS model of NTDC is kept blind to the cost of committed projects on the rationale that these projects have either already achieved financial close or are in advanced stages of construction. In the following scenario, our team included these costs in the model and ran the model to assess their financial feasibility. The results were surprising. Many of these projects were dropped by the model due to high capital or generation costs, reducing their capacity from approximately 14 GW to 8 GW, representing a 43% decrease.* PLEXOS replaces this capacity with larger shares of cheaper RE alternatives, resulting in more or less the same required investment but much higher overall cost-savings.

In this scenario, 3.5 GW of additional wind and solar capacity is added to the grid, raising their share to 37% of total installed capacity mix by 2031 with an overall cost savings of USD 8.6 Billion

Optimum Capacity Addition and Investment Required

New Capacity Built: 41.4 GW
Total Investment Required: $38.5 Billion

17.7 GW
$9 Billion

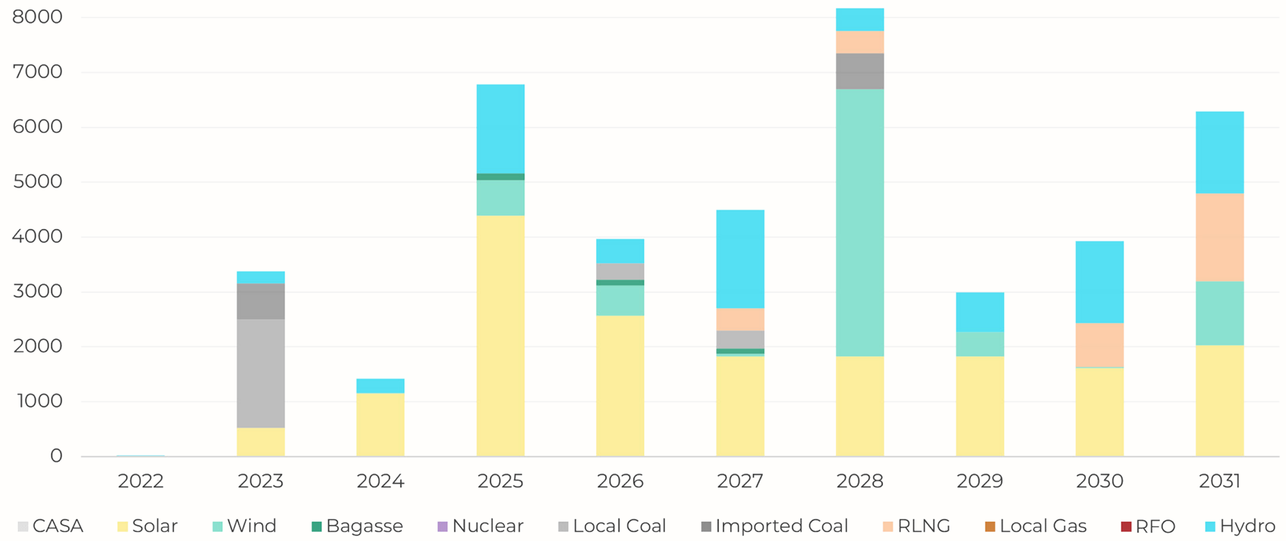
7.7 GW
$13.6 Billion

8.4 GW
$8 Billion

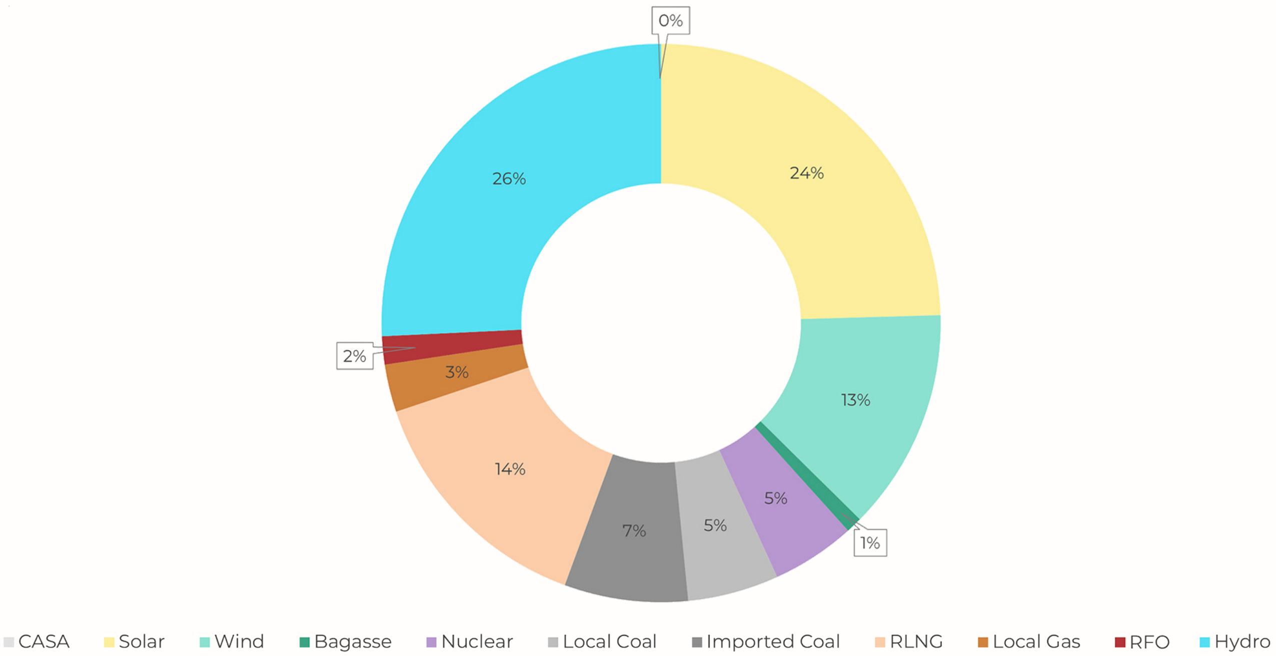
Candidate Projects (MW)												
Fiscal Year	Hydro	Imported Coal	Local Coal	RLNG	Nuclear	Bagasse	Solar PV	Wind	KE Local Coal	KE Solar PV	KE Wind	Capacity Addition/ Year
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	10	0	0	0	0	0	500	0	0	0	0	510
2025	5	0	0	0	0	100	3870	500	0	150	50	4675
2026	8	0	0	0	0	100	2050	500	0	150	50	2858
2027	0	0	0	400	0	100	1300	0	330	150	50	2330
2028	414	660	0	400	0	0	1300	4822	0	150	50	7796
2029	719	0	0	0	0	0	1300	401	0	150	50	2620
2030	1490	0	0	800	0	0	1092	0	0	150	22	3554
2031	1194	0	0	1600	0	0	1508	1116	0	150	50	5618
Total	3840	660	0	3200	0	300	12920	7339	330	1050	322	29961

Optimized Committed Projects (MW)										
Fiscal Year	CASA Import	Local Coal	RLNG	Hydro	Bagasse	Solar PV	Imported Coal	Net Metered Solar	Wind	Capacity addition/Year
2022	0	0	0	20	0	0	0	0	0	20
2023	0	1980	0	217	0	150	660	370	0	3377
2024	0	0	0	255	0	282	0	370	6	913
2025	0	0	0	1608	32	0	0	370	94	2104
2026	0	300	0	441	0	0	0	370	0	1111
2027	0	0	0	1800	0	0	0	370	0	2170
2028	0	0	0	0	0	0	0	370	0	370
2029	0	0	0	0	0	0	0	370	0	370
2030	0	0	0	0	0	0	0	370	0	370
2031	0	0	0	300	0	0	0	370	0	670
Total	0	2280	0	4640	32	432	660	3330	100	11474

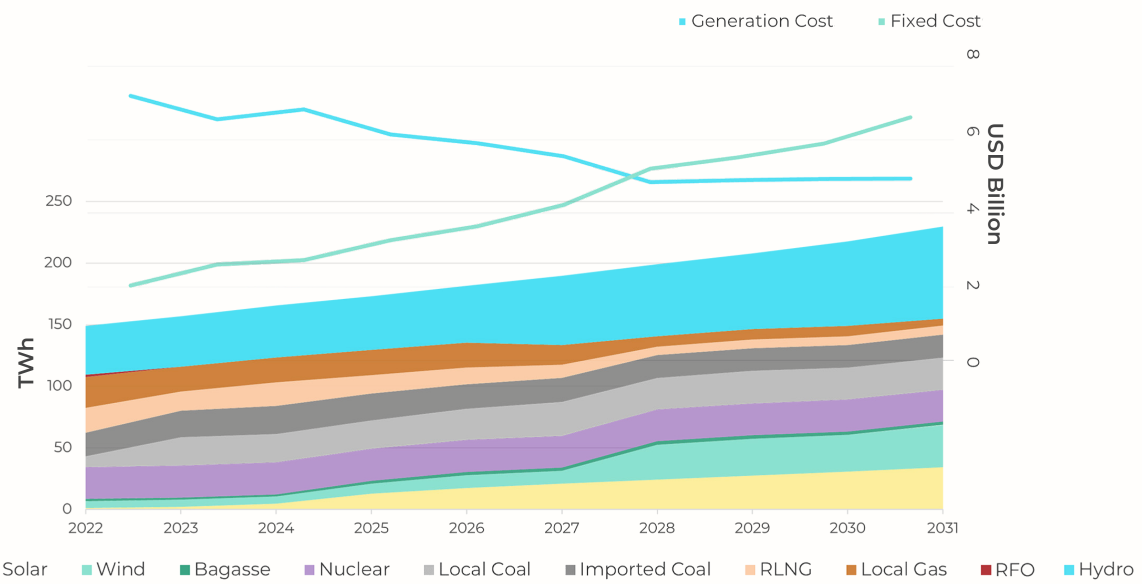
* While Net Metered Solar projects have been listed here alongside committed projects, and are also treated as such, they are not a formal part of this category in the IGCEP. Therefore, their capacity is not reflected in figures related to committed projects.



Yearly Capacity Additions to the National Grid (MW)



Capacity Mix - 2031



Generation Mix Projections - Committed Projects

Unconstrained VRE Scenario with Merit-Based Committed Projects

In the unconstrained Variable Renewable Energy (VRE) scenario, utility-scale PV and wind power projects are added without annual limitations. Solar and wind energy are treated as committed and dispatchable sources, ensuring reliable power output for effective grid integration. By removing yearly constraints on candidate projects and allowing PLEXOS to optimize them, our model incorporates an additional 11 GW of wind and solar capacity. This, combined with the previously included 13 GW and 5.5 GW, demonstrates a total potential of 39 GW accounting for 47% share of renewable energy in the national grid by 2031. The scenario offers substantial cost savings of nearly USD 10 Billion over 10 years, with ongoing fuel savings of approximately USD 180 Million annually, highlighting the long-term economic benefits in the power sector.

Optimum Capacity Addition and Investment Required

New Capacity Built: 49.5 GW
Total Investment Required: $40.2 Billion

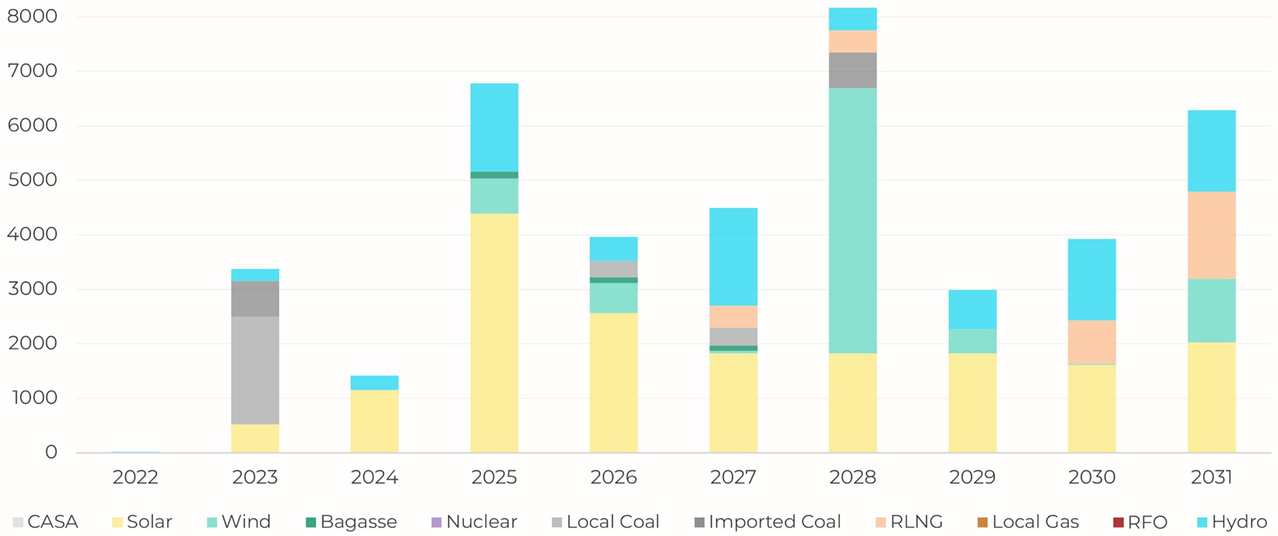
32.4 GW
$18.5 Billion

4 GW
$4.78 Billion

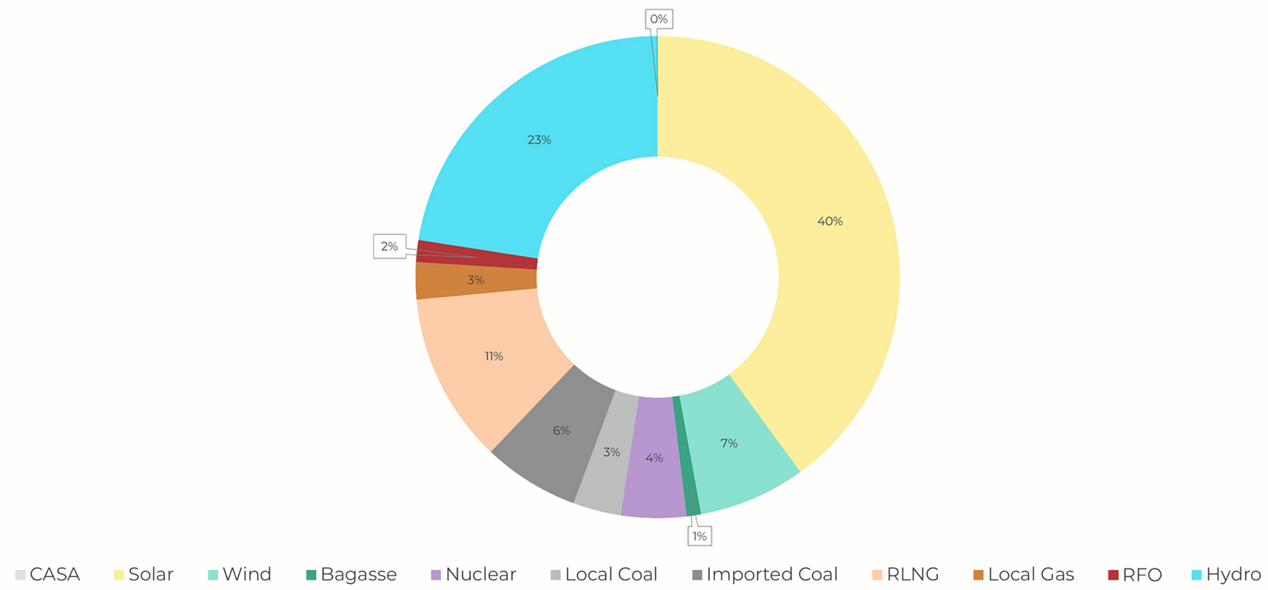
7.8 GW
$12.3 Billion

Candidate Projects (MW)												
Fiscal Year	Hydro	Imported Coal	Local Coal	RLNG	Nuclear	Bagasse	Solar PV	Wind	KE Local Coal	KE Solar PV	KE Wind	Capacity Addition/Year
2022	0	0	0	0	0	0	0	0	0	0	0	0
2023	0	0	0	0	0	0	0	0	0	0	0	0
2024	10	0	0	0	0	0	500	0	0	0	0	510
2025	5	0	0	0	0	0	11794	3379	0	853	684	16715
2026	0	0	0	0	0	0	2999	0	0	0	0	2999
2027	8	0	0	800	0	100	0	0	0	0	0	908
2028	493	660	0	400	0	100	4418	0	0	724	0	6795
2029	598	0	0	0	0	0	59	0	0	0	0	657
2030	1490	0	0	0	0	100	30	0	0	556	0	2176
2031	1015	0	0	800	0	100	6637	0	0	162	0	8714
Total	3619	660	0	2000	0	400	26437	3379	0	2295	684	39474

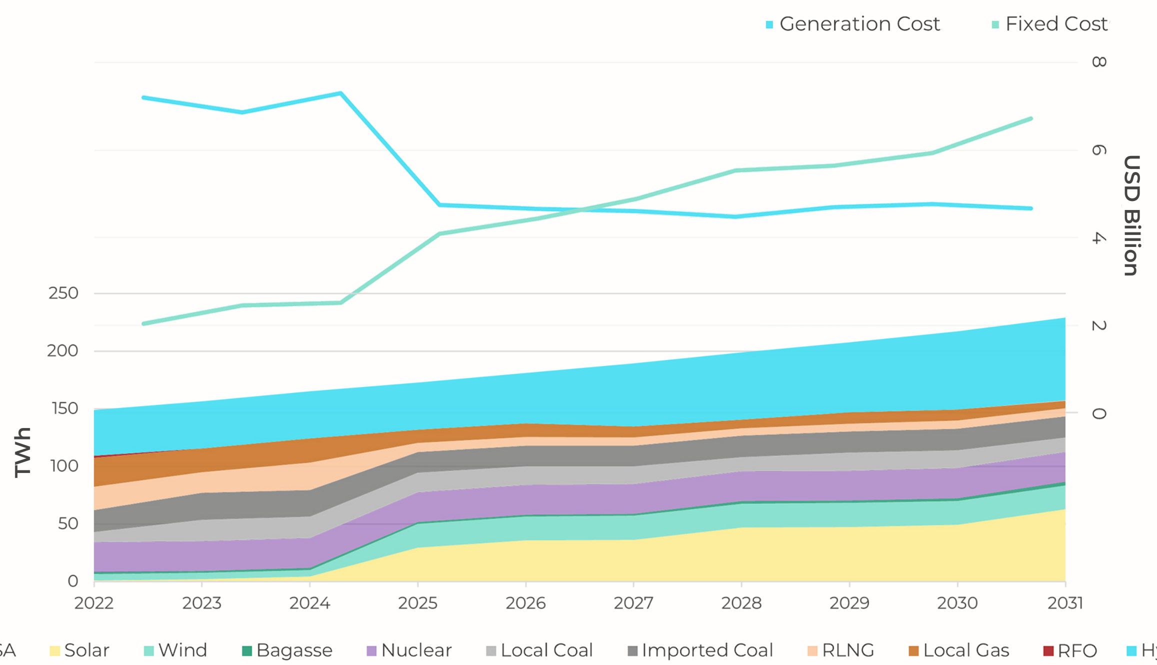
Committed Projects (MW)										
Fiscal Year	CASA Import	Local Coal	RLNG	Hydro	Bagasse	Solar PV	Imported Coal	Net Meter	Wind	Capacity Addition/ Year
2022	0	0	0	20	0	0	0	0	0	20
2023	0	1320	0	217	0	150	660	370	0	2717
2024	0	0	0	34	0	282	0	370	6	692
2025	0	0	0	0	0	0	0	370	0	370
2026	0	0	0	1380	0	0	0	370	0	1750
2027	0	0	0	2329	0	0	0	370	0	2699
2028	0	0	0	300	0	0	0	370	0	670
2029	0	0	0	0	0	0	0	370	0	370
2030	0	0	0	0	0	0	0	370	0	370
2031	0	0	0	0	32	0	0	370	0	402
Total	0	1320	0	4279	32	432	660	3330	6	10059



yearly Capacity Additions to the National Grid (MW)



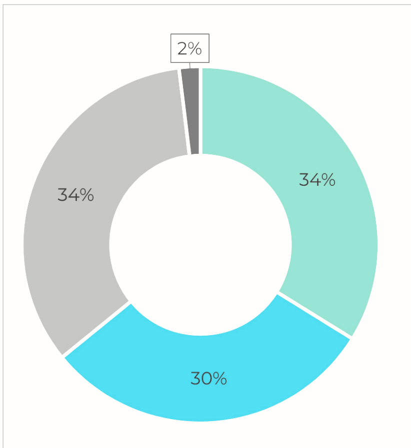
Capacity Mix - 2031

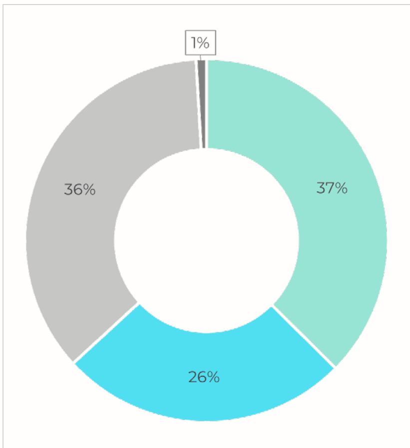


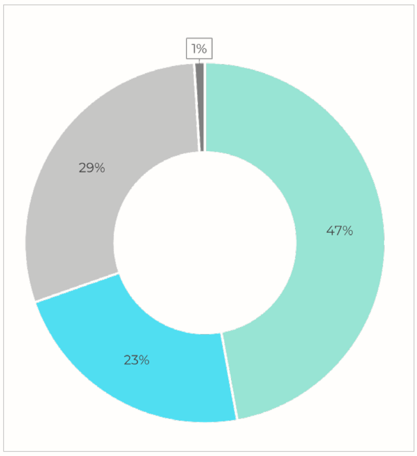
Generation Cost Projections - Unconstrained VRE

Scenario 1 Base Case	Scenario 2 Treating Committed Projects as Candidate	Scenario 3 Unconstrained VRE with Merit-Based Committed Projects

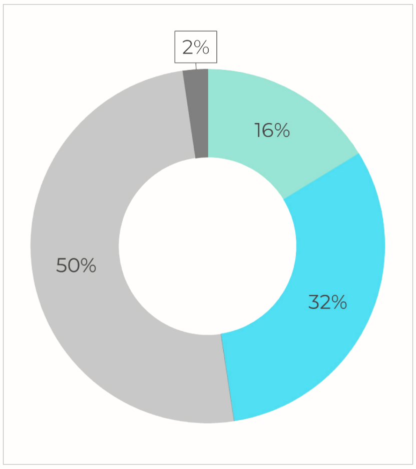
Capacity Mix by 2031

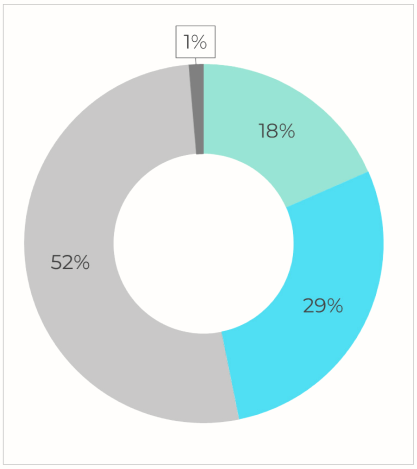


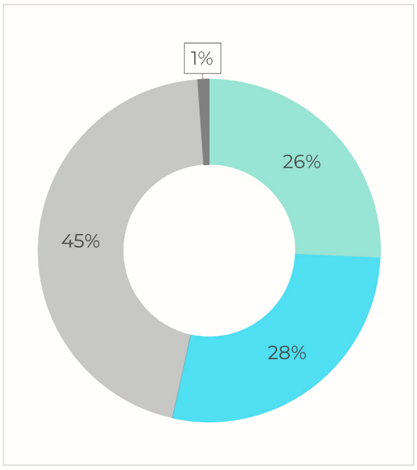




Generation Mix by 2031

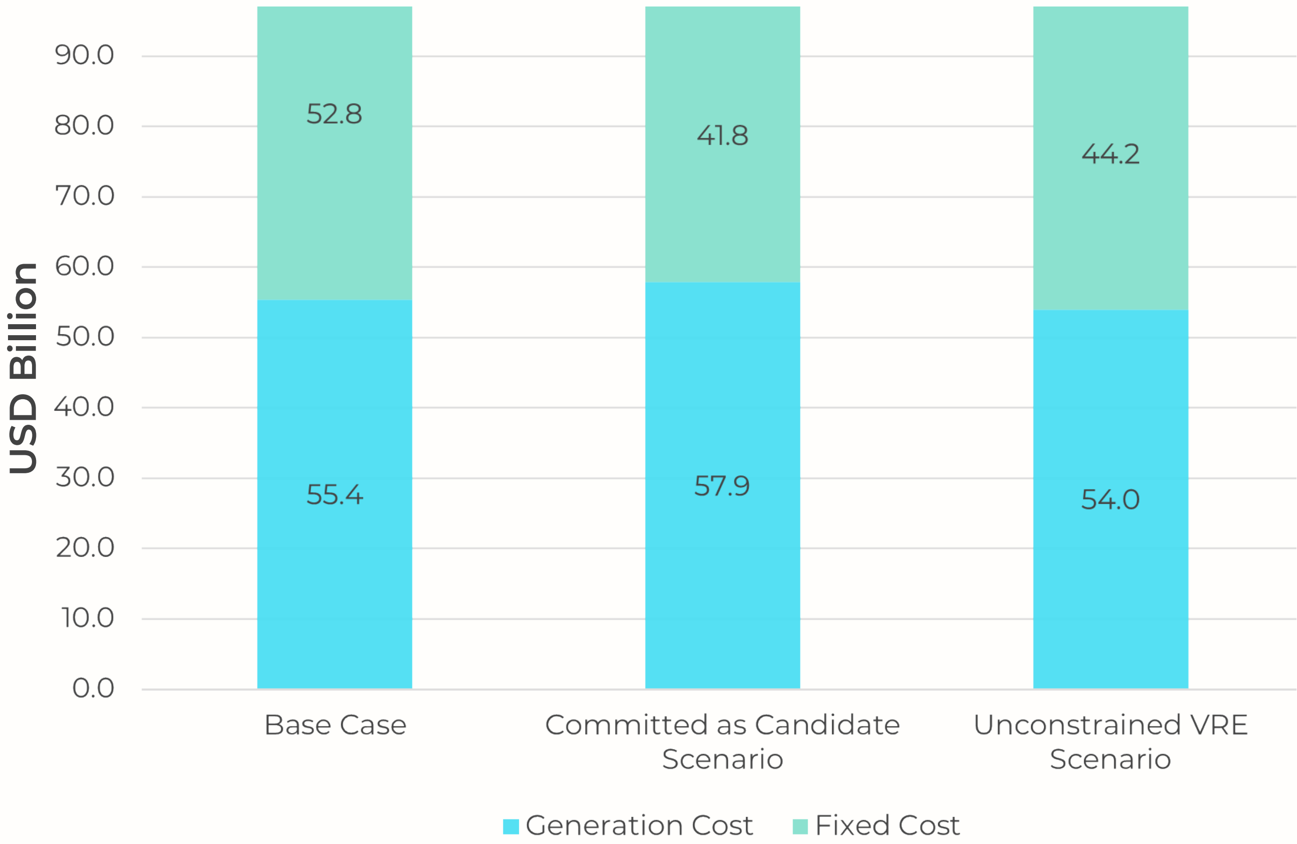






■ Solar/Wind ■ Hydro ■ Thermal ■ Other

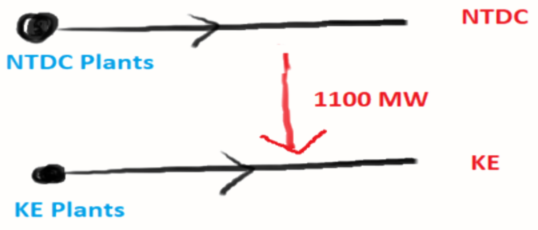
Total Costs for Each Scenario



Central Dispatch Scenario

In NTDC's current approach, both dispatch and expansion planning for KE and NTDC systems is carried out separately. A limited quantum of electricity (1100 MW) is allowed to flow the latter to the former. This approach results in cost-discrepancy between the two systems. In this scenario, we allowed unrestricted flow from NTDC to KE, resulting in what is called a central dispatch configuration.

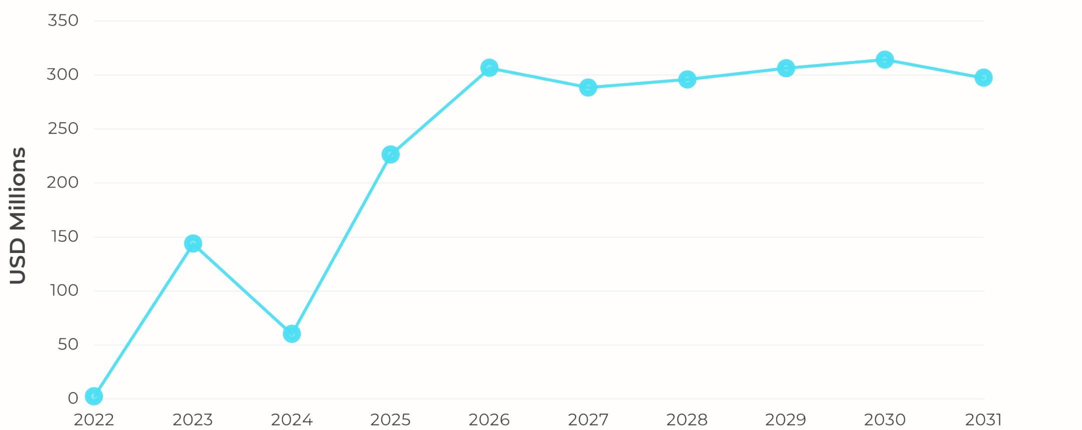
Our results indicate a 46% drop in electricity off-take from KE plants in a central dispatch configuration compared to business as usual where electricity transfer is limited to 1100 MW. This indicates that the cost of electricity generation in the KE system is much higher than the NTDC system. While electricity is drawn from expensive KE plants on economic merit, much cheaper plants remain idle in the NTDC system. Our results indicate that by restructuring our power sector approach to adopt central dispatch can save the country nearly USD 2.2 billion in the next 10 years and continue to save USD 580 million beyond the 10-year horizon.



Central dispatch scenario

Business as usual scenario

Displacement of electricity off-take from KE plants in a central dispatch scenario

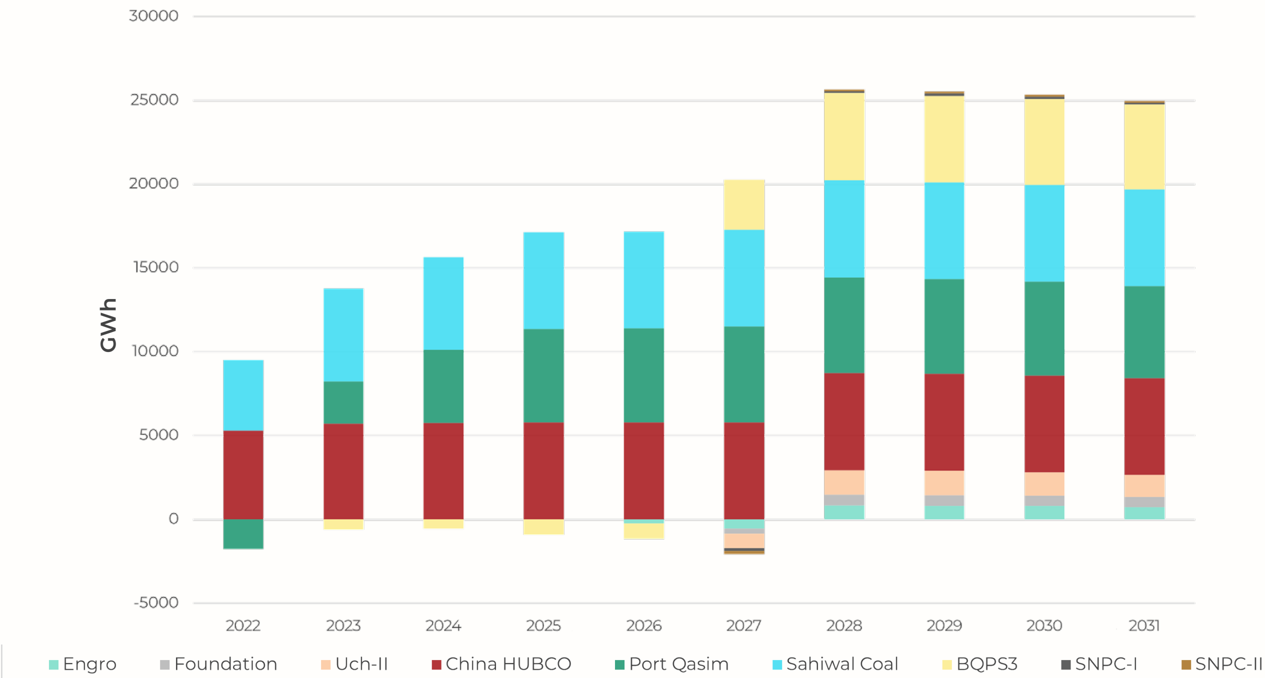


Cost savings resulting from displacement of expensive electricity by NTDC's cheaper generation

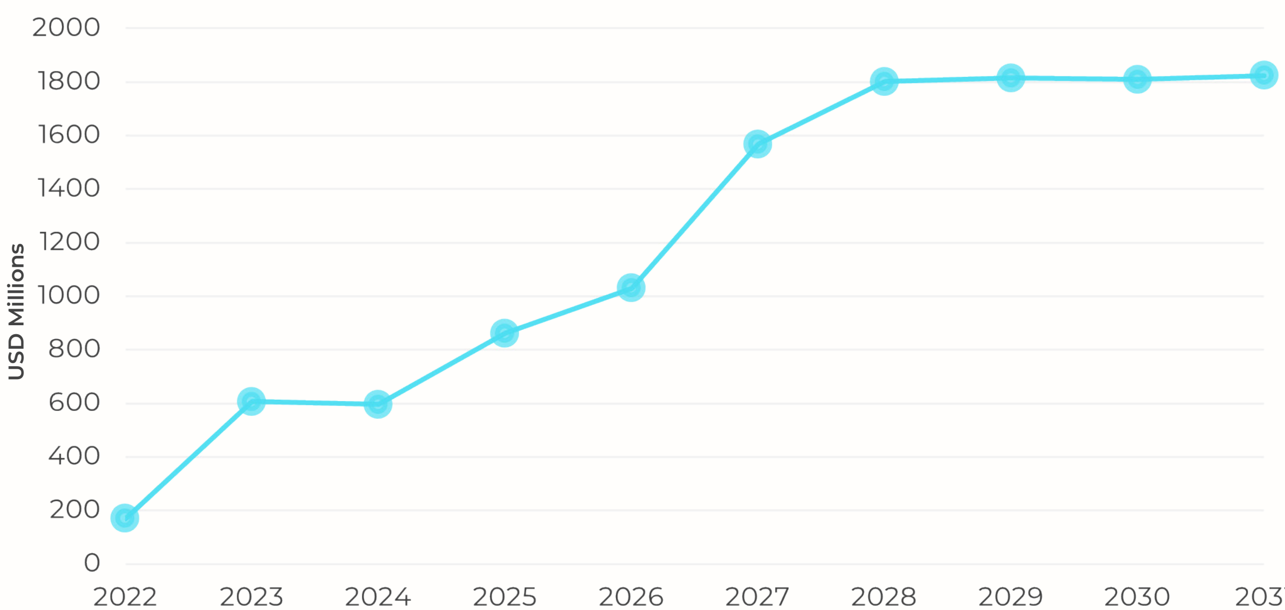
Cost of Minimum Off-Take Obligations of 9 Thermal Power Plants

In this particular scenario, we removed minimum off-take obligations for just 9 thermal plants out of more than 150 power plants in the NTDC-KE system. The motivation behind this scenario was to get an idea about the costs which such obligations impose on the consumer.

Our findings reveal that if the minimum off-take obligation for just these 9 plants (5776 MW) are removed, 65% of their generated electricity (214 TWh) is displaced to cheaper alternatives. This displacement of expensive thermal electricity also results in savings of USD 12 Billion over the next 10 years and continues to save USD 2.7 Billion in each subsequent year.



Displacement of electricity off-take from 9 thermal plants in the absence of minimum off-take obligations



Cost savings resulting from displacement of expensive electricity of 9 thermal plants by cheaper existing alternatives

11, 3rd Floor, Executive Complex,
G 8 Markaz, Islamabad
UAN: +92 51 8773676
For more info, visit our website
https://renewablesfirst.com.pk/

PRIED
Flat No: G-15, Block No: 4
1st Floor, Al-Mustafa Apartments,
G-8 Markaz, Islamabad
UAN: +92 51 8440512
For more info, visit our website
https://www.priedpk.org/