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Research Article

Prospects of low carbon development for Pakistan's energy and power sector in the post Covid scenario

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Abstract. In the backdrop of COVID19 recovery, Pakistan is still struggling to cope with the economic challenges and disruptions caused in the energy supply chain. On one hand where COVID has brought serious socio-economic costs and prolonged delays, it has also provided opportunity for developing countries such as Pakistan to "build-forward-better" their economies in a more sustainable and climate friendly manner. This study particularly highlights the impact of COVID on energy supply and demand sectors of Pakistan, its near- and long-term impacts, and what policy interventions can be adopted to put Pakistan on-track to achieve its Nationally Determined Contributions (NDCs). The economic focus in on "Green Recovery" and what key interventions will foster a rapid transition towards decarbonization in Pakistan. Low Emission Analysis Platform (LEAP) model is used to provide energy sector outlook (2020-2040) of Pakistan under different scenario i.e., Pre COVID growth, Business-as-Usual, Slow Recovery, and Green Recovery from COVID. The results obtained from the model depicts that following a green recovery scenario, Pakistan can reduce around 10 Mtoe (9%) of its total energy use, 53 TWh of electricity, 19 Mt of emissions from demand sectors, and 11 Mt of emissions from the power sector by 2030. For total levelized cost of the power sector, the green recovery scenario represents a generation cost of $13 billion by 2030 which further highlights that energy efficiency could lead to cost savings of approximately $3 billion each year by 2030. Green recovery is however still a daunting task as it would require economic stimulus of $8 billion only to recover to its pre COVID scenario and total investments of $120 billion by 2030.

Keywords: Nationally Determined Contributions; Renewable Energy, Clean Energy Transition, Energy Policy; Decarbonization; Low-Carbon Development; Energy Efficiency and Conservation; COVID 19

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1. Introduction

COVID 19 has highlighted that energy is critically essential for driving the economic growth in developing and emerging countries. Access to affordable, reliable, and clean energy is relevant to all Sustainable Development Goals (SDGs) including those are relevant to health and education for all (Senthilkumar, Reddy and Subramaniam, 2020). Recent years have observed an energy transition across many countries that are trying to opt for a sustainable pathway that is highly advocated by transitioning away from use of fossil fuels to adoption of clean energy sources, energy efficiency, and conservation measures (Steffen *et al.*, 2020). However, COVID has posed a major challenge especially for developing and under-developed countries by putting them under an economic burden which limits their mobility to finance this transition (Javed, 2021). Development in Conference of Parties (COP26) have also highlighted that the developed countries failed to deliver their $100 billion climate finance to developing economies for their battle against climate change (Arora and Mishra, 2021). Therefore, to the overcome this economic challenge and the increasing cost of a delayed recovery, many countries have opted for economic stimulus and green recovery packages. On one hand where this global pandemic has halted the global operation, it also provides an opportunity for recovering in a more resilient and sustainable manner (Aslam, Nazir and U. Zia, 2021).

Before COVID, the energy sector of Pakistan was already suffering from extensive use of imported fossil fuels, inefficiencies, high degree of transmission and distribution losses, and financial debts (Ur *et al.*, 2020). COVID has further added to this increasing burden through demand reduction and disruption in energy supply chain (Aslam *et al*, 2021). These impacts were faced by all key sectors including public entities, private sector SMEs and MSMEs, residential and commercial consumers, and transport mobility. Although when compared to other countries with similar economies, Pakistan had a better control and spread of virus, the impacts were transitional and wide-spread and virus still looms across many parts of the country (UNESCAP and Climate Analytics, 2021). During fully imposed lockdown in March 2020, Pakistan's electricity demand as per the Central Power Purchasing Agency (CPPA) dropped by 30-40%. The largest drop of 75% was observed in commercial sector, followed by 65% in Industrial (Waleed,

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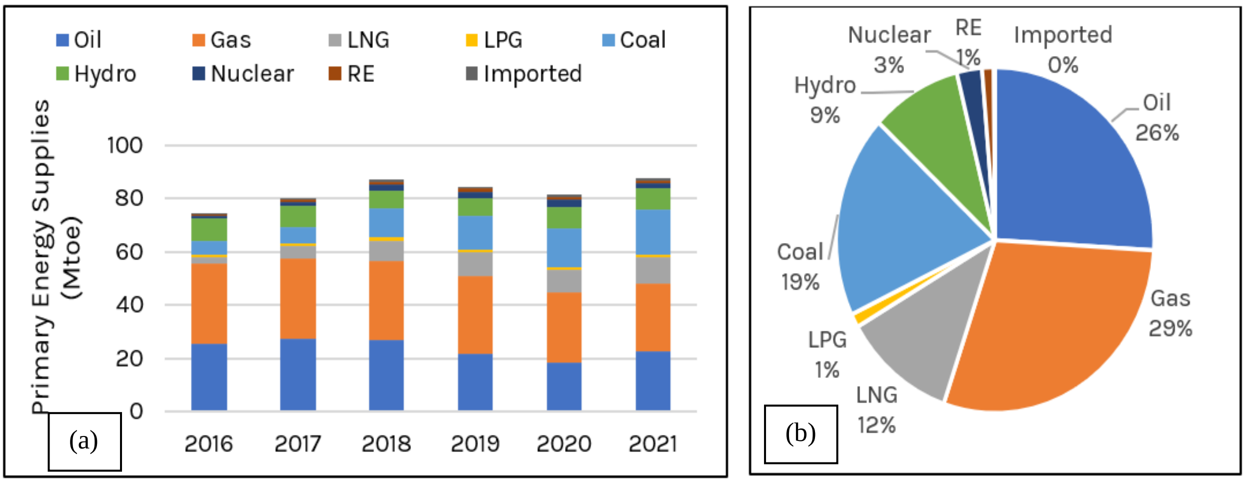

Fig 1 a) Total Primary Energy Supplies of Pakistan from different sources. b) Share of different sources in TPES in 2020-21

2020). The demand of residential sector increased, but since 70% of recoveries and bills were government subsidized and the total revenues were majorly impacted, the crisis could not be averted. According to NEPRA State of Industry Report 2021, the recoveries of distribution companies (DISCOs) in April 2020 was only 61% against a value of around 90% in the previous year (NEPRA, 2021). For distribution networks, the increased demand in residential sector also pushed a larger load on local transformers, while the maintenance workers were not able to perform recommended actions in the wake of partial or fully imposed lockdowns (Aslam *et al,* 2020).

By the end of 2020, Pakistan's circular debt was around PKR 2.36 trillion and according to Pakistan's Cabinet Committee on Energy (CCOE), PKR 260 billion was added only between July 2020 to April 2021. It is expected that without any surgical actions, this amount is expected to cross PKR 4.7 trillion by 2023 (Kiani, 2021). Further burdened by poor evacuation capacity and high losses, the capacity payments of Pakistan were around PKR 900 billion in 2020, and considering the projects in pipeline, they are estimated to cross PKR 1.5 trillion by 2023 (Aslam *et al,* 2020). Due to T&D losses, DISCOs of the country are experiencing an annual average loss of PKR 213.5 billion thus adding to national exchequer and an already burdened economy (NEPRA, 2021). Figure 1 highlights that the total energy supplies of Pakistan are highly dominated by Imported fossil fuels, and renewables (Including Hydro) constitutes less than 30% share in TPES.

Despite being a country with a very low carbon footprint (0.98 Metric ton/capita), Pakistan is among the top 10 countries that are most vulnerable to the impacts of climate change (Germanwatch, 2021). Between 1971 and 2020, the CO_2 emissions of Pakistan increased from 18 million tons to around 217 million tons (Group, 2020). Between 2012 and 2017, the per capita carbon emissions of Pakistan grew by around 8.5%. In 2018, Pakistan was ranked 19th (out of 181), with an annual fatality rate of 0.3/100,000 inhabitants (Climate Transparency, 2020). Under this context, this section therefore describes in detail the contribution of different sectors in the total emissions of Pakistan, and what targets have been defined by the government of Pakistan to curb these emissions. In 2022, Pakistan has experienced intense heatwaves causing temperatures to reach approximately 50 degree-centigrade in some areas across the country (Rosane, 2022). The high temperature has further resulted in both, an increased demand of energy resources and acute water shortages. Total GHG emissions of Pakistan currently stand at 438 million tons of $CO_{2\text{-}eq}$. with energy sector contributing to the largest share of approximately 211 Mt (MoCC, 2021).

Now, according to the revised NDCs, Pakistan has committed to reduce its GHG emissions by 15% till 2030 using country's own resources and 50% by 2030 depending on the availability of international finance (ibid). As per the NDCs, the key priority actions for achieving these targets are i) 60% shift to clean energy by 2030, ii) 30% shift to EV sales by 2030, iii) Coal Moratorium and Shelving two coal fired projects, iv) TBTTP and BTAP projects for forestation, v) Recharge Pakistan program for disaster resilience, and vi) protected areas initiative which aims to increase the cover from 12% to 15%.

The existing challenges of Pakistan's energy sector in 2021 have highlighted the ever-increasing need for indigenization of energy resources and making a shift sustainable energy growth. It will not only help Pakistan in improving its environment profile, but also assist the country in carving a way out of the existing financial trap. With recent advancement in technology, renewables are now the cheapest source of energy. As per the cost reported by Statista, the cost of solar PV and wind declined from $378 and $86 per MWh in 2010 to $60 and $53 per MWh in 2019 (Armstrong, 2021). Even in Pakistan, after NEPRA tariffs of 2018, power tariffs for wind and solar energy have significantly reduced and an average wind and solar power unit is produced at approximately $0.0486/kWh and $0.034/kWh respectively (Aslam, Nazir and U. ur R. Zia, 2021). The need for energy transition in Pakistan, however, goes beyond the power sector to other key areas specially the demand side management through energy efficiency and conservation measures, providing energy access to the deprived communities through off-grid solutions, and decarbonization in the industrial and transport sectors.

In the backdrop of challenges described above, it is extremely critical for Pakistan to analyze the impacts of COVID and identify key measures that can pave a way forward for a sustainable recovery while make socio-economic and just transition case. This study therefore performs the impact assessment of COVID on Pakistan's energy sector while examining the potential of a green recovery to lead a transition followed by green jobs, a structural decline of emissions, clean energy adoption, and a spur of economic growth.

2. Reform Priorities of Pakistan's Energy Sector in COVID and Post COVID Era

2.1. Economic Response to COVID

During COVID, Pakistan put forward several initiatives to support common citizens. To counter sharp inflation and the economic turmoil, Pakistan's central bank reduced the monetary policy rate from 13.2% to 7%. A 180-day extension of loan settlements was also offered to importers and exporters of the county by 180 days (IMF, 2020). The monetary and fiscal stimulus measures of Pakistan include SMEs support of PKR 180 million on credits, reduction in marginal cost requirements from 30% to 10%, Sukuk bond on PKR 700 million, and a reduction in DBR from 50% to 60% for consumer loans. Stimulus package of around PKR 1.2 trillion was released through a multi-sectoral relief package which includes relief of PKR 200 billion for daily wagers, cash transfer of PKR 150 billion to low-income families, PKR 100 billion for tax refunds, PKR 70 billion for fuel pricing relief, and relief packages for procurement of wheat and financial support of agriculture. For energy sector, a PKR 110 billion relief was given in power bills, and around PKR 100 billion for emergency energy provisions (IMF, no date; Aslam and Sheikh, 2020; UNIDO, 2020; Javed, 2021).

For a green recovery, Pakistan has recently leaped forward towards combatting climate change through its Ten Billion Tsunami Tree Project (TBTTP) which has provided green jobs to around 65,000 people (*Pakistan Economic Survey 2020-21*, 2021). Under "Pakistan Hydromet and Ecosystem Restoration Services Project", Pakistan has signed a $188 million project. Further, the world bank group has also approved a repurposing of $180 million for nature conservation in Pakistan (ibid). For green financing, finance ministries are working on "Debt for Nature" Swap schemes targeting $1 billion finance. Pakistan's first Green Euro Bond of $500 million was recently launched for hydro power development in the country (Aslam, Nazir and Zia, 2021).

2.2. Key Policy Interventions for the Energy Sector

Over the past 5 years, the energy sector of Pakistan has undergone an ambitious shift in its policies, ranging from interventions for the power sector, electricity markets, electrification programs, and electric vehicles to energy efficiency and conservation. Table 1 highlights the key actions in terms of policies and regulations that Pakistan have taken to support its ambition of energy transition. This indicates that since 2019, Pakistan has witnessed a renewed interest towards clean energy transition under its policy and regulatory framework. With Alternate and Renewable Energy Policy targeting a renewable energy share of 30% by 2030, Pakistan also proposed ambitious targets for clean energy under its Nationally Determined Contributions (60% by 2030 including Hydro) and Indicative Generation Capacity Expansion Plan (60% by 2030 including Hydro).

2.3. Need for an Evidence based Integrated Energy Planning

In times of energy transition and economic recovery, evidence and reliable data play a critical role for a well-informed policy decision. An informed policy making process involves both qualitative and quantitative inputs from all relevant stakeholders through the cycle. Along with integrating evidence into the policy making process, it also involves using the gathered evidence in the most appropriate and transparent manner. Since decision making in the energy sector is a highly integrated process, it must ensure that the interdisciplinary impacts on other sectors are analyzed as well. In a national context, Pakistan lacks access to reliable numbers and data on which the policies are based. For Pakistan to achieve its energy transition goals (mainly prescribed under ARE Policy 2019, IGCEP 2021, EV Policy, NDCs, SDGs, etc.), the energy system must be transformed greatly.

Mirjat *et al.*, (2018) performed a demand and supply forecast of Pakistan's energy sector from 2015-2050 and predicted that the demand is expected to increase with an annual compound growth rate of 8.13%. However, by adopting energy-efficient measures, a reduction of around 20% in demand can be achieved. However, the model was unconstrained, and the study had some limitations in the context of capacity that needs to be fixed for the committed power plants. Usama et al. (Perwez *et al.*, 2015) performed demand-side forecasting of Pakistan's energy sector under three different scenarios of

Table 1
Key Policy Reforms of Pakistan's Energy Sector to comply with Paris Agreement Goals

Sr. No	Policy/Regulation	Key Interventions
1	Alternate and Renewable Energy Policy (2019) (AEDB, 2019)	The ARE policy 2019 aims to safeguard the environment by increasing the share of renewable energy resources in the energy mix of Pakistan. Under this policy, Pakistan has set a target to achieve a 20% generation from renewables (Solar, Wind, Biomass, MHPPs, etc.) by capacity by 2025 and 30% by 2030.
2	Indicative Generation Capacity Expansion Plan 2021 (NTDC, 2022)	This plan defines Pakistan's future expansion of the power sector. Under this plan, Pakistan aims to achieve a clean energy generation share above 60% by 2030.
3	Coal Moratorium 2020 (Climate Transparency, 2020)	In 2020, Pakistan announced the moratorium of coal-based power generation in Pakistan. As per this intervention, no new coal power plant will enter the capacity pipeline.
4	Updated Nationally Determined Contributions (NDCs) (MoCC, 2021)	In 2021, Pakistan submitted its updated NDCs as its pathway to reach the goals of the Paris agreement. Under the revised NDCs, Pakistan has set an un-conditional target of 15% emission reduction from the country's own resources, and a conditional target of 50% emission reduction based on availability of international finance.
5	Competitive Trading Bilateral Contracts Market (CTBCM) (Ismail, 2019)	Under CTBCM model, Pakistan has transitioned from a single buyer to a multi-buyer model. This transition is expected to provide transparency, flexibility, and accountability in the power market while enabling renewable energy to compete fairly with fossil fuel-based power producers
6	National Electricity policy 2021 (Mustafa, 2021)	NEP 2021 was approved by Pakistan's Council of Common Interests in 2021 to ensure that power expansion in the country is competitive, transparent, and has the least cost. The policy envisions to ensure a country-wide access to electricity through a self-sustained power sector.
7	National Energy Efficiency and Conservation Policy 2022 (Draft)	This policy will provide key insights and interventions for integrated activities & investments required to remove institutional, capacity, technical, and capacity building issues relevant to energy efficiency and conservation in Pakistan.
8	National Electric Vehicle Policy (Zia and Aslam, 2022)	Initially drafted by MoCC, this policy aims to achieve a share of 30% from electric vehicles in total sales by 2030. Some key aspects of the policy were later redefined through an updated draft by the Engineering Development Board (EDB).

Business as Usual (BAU), "New Coal", and "Green Finance" However, this study did not account for the change in residential living patterns i.e. the increase in per capita income and reduction in household sizes. The study done by Rehman *et al.* (Rehman *et al.*, 2017) took only GDP assumptions as the driving factor of the forecast. Though research has good insights, consumer and population growth patterns should have been incorporated in the model. Gul and Qureshi, (2012) did incorporate all the three key assumptions, however, apart from the methodology, the power sector of Pakistan has taken a major shift now from what it was in 2009 (the study year).

As opposed to these studies, most global models for the power sector have highlighted the significance of an integrated energy plan for evidence-based energy modeling. However, it is critical for any capacity plan to incorporate all technical limitations. A major limitation with current research is that most of the studies are entirely focused on the power sector and does not incorporate the demand consumption patterns (primate energy supplies) in Transport, Industrial, and Building sector. Research studies have indicated that since these sectors are interconnected, an inclusive modeling approach for policy formulation should be driven by a complete integrated demand and supply equilibrium (Capros *et al.*, 2019).

In the era of big data analytics, data mining & learning-based methodologies; Zia *et al.*, (2019) highlighted the importance of such modeling tools in policy formulations and stresses that the scenarios-based modeling may serve to provide better and quicker policy pathways for energy transitions. Tools that have been most commonly used for this exercise are ENPEP BALANCE, LEAP, MESSAGE, and MARKAL/TIMES. ENPEP has been used for analyzing electric power options, energy, and environmental assessment and providing a long term GHG emission outlook (Bernstein, Hassell and Hagen, 1999; Mirsagedis *et al.*, 2004; Conzelmann and Koritarov, 2008). MESSAGE has mostly been used for performing demand-supply equilibrium and designing the long-term strategy for electricity generation (Herdinie and Sartono, 2003; Saradhi, Pandit and Puranik, 2009; Hainoun, Aldin and Almoustafa, 2010). TIMES/MARKAL is a micro model that has been majorly used to rank/select power expansion alternatives and evaluate future energy supply strategies (Akinbami, 2001; Chen and Wu, 2001; Heinrich *et al.*, 2007). LEAP has been most widely adopted by countries for sustainable power planning, designing an integrated framework, and providing long-term scenario alternatives and their implications in the electricity sector. Further, it also helps to develop energy flow charts. Kadian *et al,* (2007) used LEAP modeling for determining the total energy consumption of residential households in India. Phdungslip (Phdungsilp, 2010) used this model for analyzing the energy policy interventions in Thailand and developed a pathway for energy and carbon development between 2000-2025. A case study of energy demand and CO_2 emissions in Beijing-China by Huang, Bor and Peng, (2011) also used a LEAP model and proposed some sustainable development pathways. LEAP models have previously been used by various studies to perform scenario-based modeling and identification of key policy reforms (Shin *et al.*, 2005; Song *et al.*, 2007).

This study drives its recommendations and modeling approach through a joint collaboration of Pakistan Private Power and Infrastructure Board (PPIB), Ministry of Energy (Power Division) and Sustainable Development Policy institute (SDPI), Islamabad. This joint collaboration provided more deepfelt insights into the modeling approach as demand drivers were set after setting ground realities. The LEAP Model developed in the study has its key drivers coming from opinions of vast range of stakeholders in Pakistan's energy sector. Modeling constraints based on national commitments and targets that were recently presented by the government have not been analyzed in most studies. This model bridges that gap by developing an integrated energy model based on a demand-supply equilibrium and using the most recent government targets and plans. Further, the recent policies and committed projects of Pakistan have been analyzed by running both constrained and unconstrained models under different scenarios of recovery from COVID 19.

3. Methodology and Data Collection

For modeling the impact of COVID19 on energy sector, Low Emission Analysis Platform (LEAP) model has been designed

Table 2
Description of Modeling Scenarios for Low Emission Analysis Platform

Sr. No	Scenario	Description
1	Pre_COVID Scenario (PCS)	In this scenario, the energy sector evolves without considering the impacts of COVID19 on entire energy value chain. Pre COVID assumption prescribed under Pakistan's vision 2020, IGCEP 2047, are the key sources for driving the model. The underlying reason for modeling this scenario is to compare the post covid scenarios with a base value. This would assist in quantifying the assessment of energy, economics, and environmental profiles.
2	BAU Scenario (COVID_BAU / CBU)	Using the same policies and action plans as in the "business as usual" scenario, this scenario shows the profile that would emerge if Pakistan recovered from the scenario within a year. Since it is the most recent and officially approved version for energy sector demand analysis and power sector expansion, this scenario is benchmarked to the International Energy Agency's (IEA) fast recovery scenario and follows the targets prescribed under IGCEP 2021. The model also considers the decline in demand brought on by low rates of urbanization, slower adoption of new technologies, low rates of industrialization, and the effects of the COVID 19 forced lockdown.
3	Slow Recovery Scenario (COVID_SR / SGS)	This hypothetical scenario shows a relatively subpar response to COVID and explains the situation should Pakistan take a considerably longer period of time (3 years) to contain the pandemic. IGCEP 2021 is still in charge of this scenario's power generation, but penetration rates are significantly slower than they would be in the scenario with a quick recovery.
4	Green Recovery Scenario (COVID_GR / GRS)	This scenario depicts a more environmentally friendly method of recovering from the pandemic and one whose environmental footprint meets the goals of the Paris Agreement. This includes accelerating the adoption of efficient and clean fuel technology, reducing T&D losses, decarbonizing the industrial and transportation sectors, elevating device energy efficiencies, and—most importantly—increasing the share of renewable energy sources in the nation's power generation mix. The population, urbanization, industrialization, growth patterns, and recovery timeframe are all precisely the same as those in a quick recovery scenario; however, the way in which the economy recovers over the same time is different. It likewise follows the IGCEP 2021 plan until 2030 before rapidly transitioning to variable renewable energy sources like solar and wind.

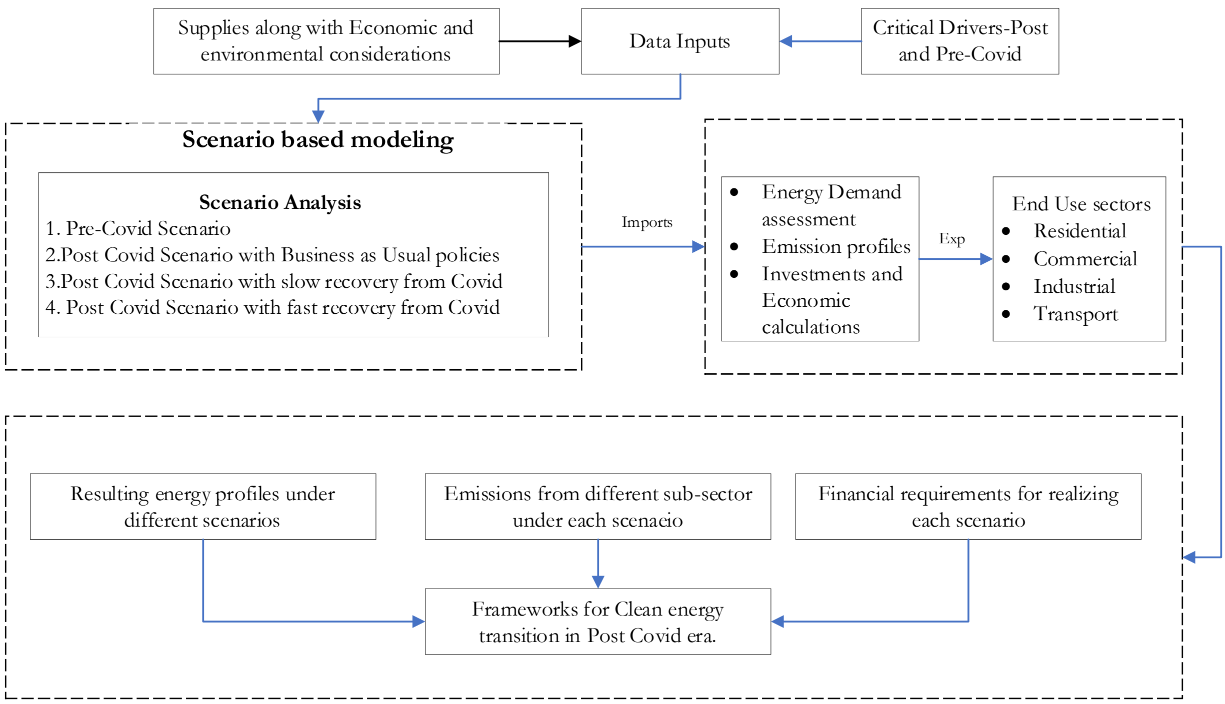

Fig 2 LEAP Modelling Framework

for both supply and demand sectors. The model operates in a demand supply equilibrium under different scenarios. While most of the data collection has been through procurement from government departments and use of secondary research, the model drivers also take significant inputs from stakeholder engagements conducted during the research phase. Three different consultations were conducted under the following themes i.e., i) Development of and SDG-7 Roadmap for Pakistan; ii) Pakistan Clean Energy Transition Summit, and iii) Impact of COVID-19 on Energy and Power Sector of Pakistan.

3.1. Scenario based Modeling Approach

To model the COVID impacts, four scenarios have been created, based on the different assumption under which Pakistan will recover from COVID19. The overarching goal is to envision how the country profiles would change over the next 25 years based on the actions it takes to combat the global pandemic. As a result, the model may also be used to monitor how long it will take Pakistan to resume its pre-COVID scenario trajectory. According to the information in Table 2, the scenarios are benchmarked using IEA modelling approaches (Agency, 2021).

Using LEAP, this study simulated the energy demand and supply of Pakistan with a special focus on environmental emission reductions. Considering the long-life span of infrastructure, 2015 has been used as the first year, 2020 as base year, and 2040 as the end year. Each sector on demand as well as supply sides has been further categorized into different subsectors as shown in modeling framework in Figure 2.

3.2. Base Year Data and Demand Drivers

FY 2015-16 has been taken as the first while FY 2019-20 as the base year. The key parameters at the supply side includes Total Primary energy supplies from different sources (Coal, Hydro, etc.), planned Capacity Additions (till 2040), and resource generation profiles. On demand side, the data is more segregated into subsectors using a to-down approach. The data values for base year modeling are attached as a supplementary file as per the different parameters highlighted in Table 3.

For energy demand calculations, following analytical approach is used:

$$TD_{b,s,t} = A_{b,s,t} \text{ x } EI_{b,s,t}$$

where TD is total demand, A is total activity level, EI is energy intensity, and b,s, and t are branch, scenario, and year (0 in base year) respectively. Each sector (and subsector) is further driven through a single or a set of parameters based upon the scenario. Some basic parameters are kept same for all scenarios while the major difference is coming from energy reform priorities and targets prescribed under different policy goals as described below.

- *Population and Urbanization:* The population growth is same for all scenarios, increasing at the rate of 2% between 2020-2040 (Economics, 2020). The urban population however increase from a current share of 37% to 50% by 2030 and 60% by 2040 as per the Pakistan Vision 2025 values (MoPD&R, 2014).
- *Gross Domestic Product (GDP):* The value of Pakistan's GDP in 2020 was $300.3 billion (Macrotrends, 2021). Under PCS, this will grow at a rate of 4.5% till 2025 and then 5.5% between 2025-40. In CBU, the GDP will grow at a rate of 4.2% from 2020-2025 and 4.5% from 2025 on-wards. In SRS, the GDP growth is benchmarked with IEA slow recovery scenario indicating an average growth rate of 3.6%. The GRS follows the same GDP growth rate as CBU.
- *Income Growth:* The income growth in PCS as per Pakistan's Demographic survey is 3%. In CBU, SRS, and GRS, the value is projected at 2.7%, 2.5%, and 2.7% respectively.
- *Annual Travel Demand and Technology Penetration:* The annual travel demand is defined as the function of GNI/capita and population growth. Technology penetration and improvements has been modeled through use of updated technologies and further penetration of existing technologies. Penetration values

Table 3
Base year Data Sets

Sr. No	Sector	Subsector	Sub-Subsectors	Reference
1	Residential	Rural-Residence Urban-Residence	• Electrified & Unelectrified households. • Electricity Consumption under Lighting, refrigeration, Pumping, etc. • Cooking Fuel and technologies (Urban & Rural). • Heating fuels and technologies (Urban & Rural). • Energy Intensity of all technologies • Activity Levels of all technologies.	(Rashid, 2016), (Aslam *et al.*, 2022), (*Pakistan Energy Year Book, 2020*, 2020)
2	Industrial	Total Energy Consumption and GDP share of different Industries Fuel share in each industry	• Food and Beverage ∣ Construction ∣ Chemical • Paper and Pulp ∣ Textile and Leather • Iron and Steel ∣ Wood Products • Others. • Oil ∣ Coal ∣ Biomass ∣ Natural Gas ∣ Electricity.	(*Pakistan Bureau of Statistics*, 2017; PBS, 2019)
3	Transport	Passenger	• Vehicle stock of all categories (2-W, 3-W, 4-W, Taxis, SUVs, Small & Big busses, Trucks, Vans, Rails, etc. • Annual Travel & Vehicle use of all categories. • Load factor for all vehicles. • Fuel Economy of all vehicle categories • Activity levels	(Ministry of Industries and Production Government of Pakistan, 2020; PAMA, 2021a, 2021b)
		Freight	• Vehicle Stock (Trucks, Railways, busses, pickups, etc.) • Annual Travel & Vehicle use of all categories. • Load factor for all vehicles. • Fuel Economy of all vehicle categories • Activity levels	
4	Commercial	Commercial Buildings	• Private Offices ∣ Government Buildings ∣ Academia ∣ Hotels ∣ Educational Institutions • Fuel consumption in each building. • Floor Space of each category • Activity Levels.	(Rashid, 2016)
5	Others	Total Fuel Consumption	• Oil ∣ Coal ∣ Biomass ∣ Natural Gas ∣ Electricity.	(*Pakistan Energy Year Book, 2020*, 2020)

are taken as per the demographic survey and NEECA Strategic Plan 2023-25 (NEECA, 2020).

- *Electricity Capacity Expansion Plan:* In PCS, the capacity expansion has been modeled as per the initial iteration of Pakistan's Indicative Generation Capacity Expansion Plan (IGCEP 2047) since it was launched before COVID outbreak in Pakistan. For CBU and SRS, the updated version i.e., IGCEP 2021 has been used. The Green Recovery scenario however follows the targets of Pakistan's Alternate and Renewable Energy Policy 2019 and Nationally Determined Contributions (NDCs) as per which Pakistan will achieve a share of 30% renewables (wind and solar) by 2030. The capacity additions as per the plan of each scenario are described in Supplementary Data file.
- *Carbon Dioxide Emissions:* For modeling emission profiles, the datasets mainly involve emission intensities of different sources taken from recent report of Intergovernmental Panel on Climate Change (GoP-CCD, 2013; IPCC, 2014). For emissions resulting through the demand sectors, the model-built in values through TED repository (benchmarked with IEA) is used. No carbon capturing technologies are used in power plants in either of the scenarios and resultantly, the emission intensities are kept same through the timeline.
- *Electricity Costing:* The values for costing profiles are taken as per the recently approved tariffs from NEPRA. Further as per the NEPRA's costing analysis, the values for coal are given for 80% of capacity factor, and the values of natural gas are given for 60% of capacity factor. The levelized cost of each source taken into consideration is mentioned in Table 4.

3.3. Model Validation and Limitations

The initial validation for basic structure of the model has been performed through comparative assessment of the energy balance obtained from the LEAP model's bottom-up approach and the energy balance as defined in Pakistan's Energy

Table 4
Levelized Cost of Electricity for different sources in Pakistan

Source	LCOE ($/kWh)	Source	LCOE ($/kWh)
Hydropower	0.051	Solar	0.036
Wind	0.039	Biomass	0.042
Coal	0.0853	Natural Gas	0.069
Oil	0.141	Nuclear Power	0.0733

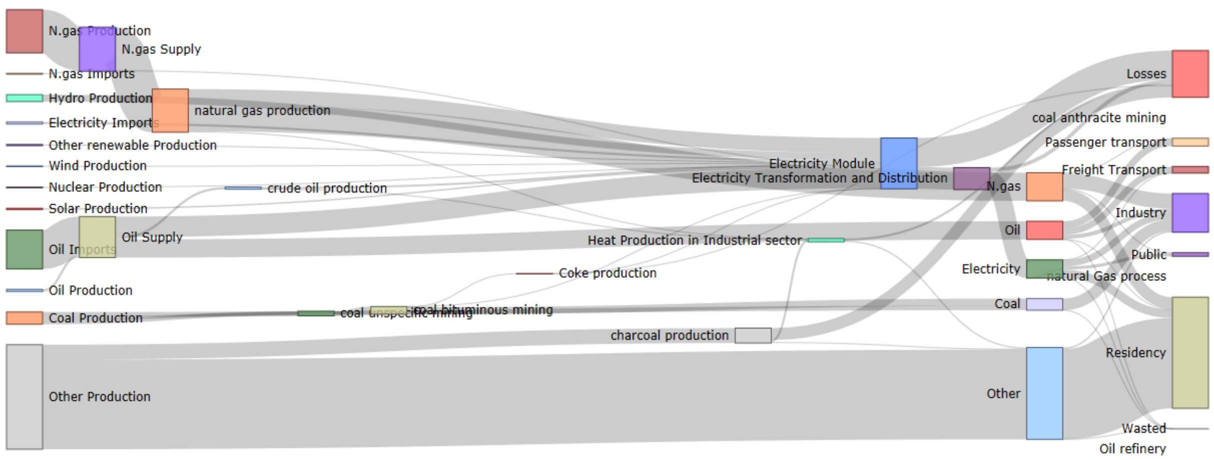

Fig 3 Sankey Diagram of Pakistan's Energy Balance in 2020

Yearbook 2020 developed by Hydrocarbon Development Institute of Pakistan. Pak-EYB is primarily the only official data source which defines the annual consumption and production of energy in Pakistan. However, since it does not define the consumption through non-commercial use of bioenergy resources in Pakistan, this value was obtained through Sankey Diagram of IEA. The total primary energy supplies of the country sum up to around 109 Mtoe while the model results indicate the based year supplies of 115 Mtoe (an error of 5.2%). Along with energy supplies, the model is also verified for the share of different fuels and energy consumption in different demand sectors using the same approach. In each case, the error was below 10% thus validating the model structure. Finally, the Sankey diagram obtained from the LEAP model was also compared with the Sankey Diagram of Pakistan published by IEA, thus further strengthening the model approach.

While the model does replicate the absolute values for the base year (Sankey diagram of energy balance shown in Figure 3), the projections are driver under a set of assumptions apart from the policy goals and targets. Key assumption and limitations of this LEAP model includes:

- Pakistan does not have any energy mix target beyond 2030 (while the end for year for model is 2040). Therefore, in PCS, CBU and SRS, the model runs under the least cost basis between 2030-40.
- For power sector emissions, only grid emissions are considered and not the emissions resulting from land use and pre-processing.
- The cost parameters do not include any social costs or cost for time overruns. This is especially the case for hydropower development.
- In GRS, the model runs under the least cost optimization without considering the cost of long-term power purchase agreements with Independent Power producers.
- Capacity payments of power plants are not part of economic calculations.
- The household energy intensity values of biomass are missing from the literature and hence, the values of neighboring countries (India, Bangladesh, or Iran) are used.
- The fuel consumption in Agriculture tractors is considered under the Transport sector.
- The non-energy use of resources is not incorporated in the model.

4. Results and Discussion

Results obtained from the LEAP model are analysed under two broader themes i.e., i) the short and long-term Impacts of COVID-19 on the energy sector and ii) how a green recovery can provide a better case for achieving long-term sustainability.

4.1. Impacts on Energy Demand

For energy sector, the most prominent impact was on energy demand and hence analysing these impacts can provide a holistic outlook and changing patterns. This change is mainly driven by the lower consumption due to imposed lockdowns, disturbed working hours, and limited travelling. Figure 4 represents the variation in this demand under different scenarios. In a slow recovery scenario, the demand has been suppressed since full economic and demand recovery has taken a comparatively longer time to recover to its pre-COVID state. In a green recovery scenario, the demand is even further below the slow recovery as energy efficiency measures adopted have reduced the overall demand. This includes the use of energy efficient appliances in the residential sector, fuel efficiency improvement and use of electric mobility in transport sector, and heat recovery and efficiency improvements in the Industrial sector. Similar patterns of energy demand suppression were witnessed in almost all countries. International Energy Agency also indicated that the global energy demand during COVID dropped by almost 4%. Even when the restrictions were removed, the economies showed recovery patterns that were below the pre-COVID projected growth rates (IEA, 2022).

The model's calculation of the energy demand profile shown in Figure 5 involved adding the energy demands of each subsector, including residential, commercial, transportation, and industrial. The GDP growth, technology utilisation, and their associated causes are additional factors that contribute to the differences in values observed for each scenario. According to this estimate, the 68 Mtoe energy demand in 2019 was predicted to increase to 143 Mtoe by 2030 and 213 Mtoe by 2040. This demand would be capped at 115 Mtoe by 2030 (28 Mtoe less than in PCS) and 160 Mtoe by 2040 under the CBU scenario. According to the green recovery scenario, the energy consumption by 2030 is constrained to 104 Mtoe, which shows that compared to the CBU scenario, energy savings of roughly 10 Mtoe or 9% have been achieved. The model also shows how each sector's and its subsectors' energy demand changes depending on the scenario.

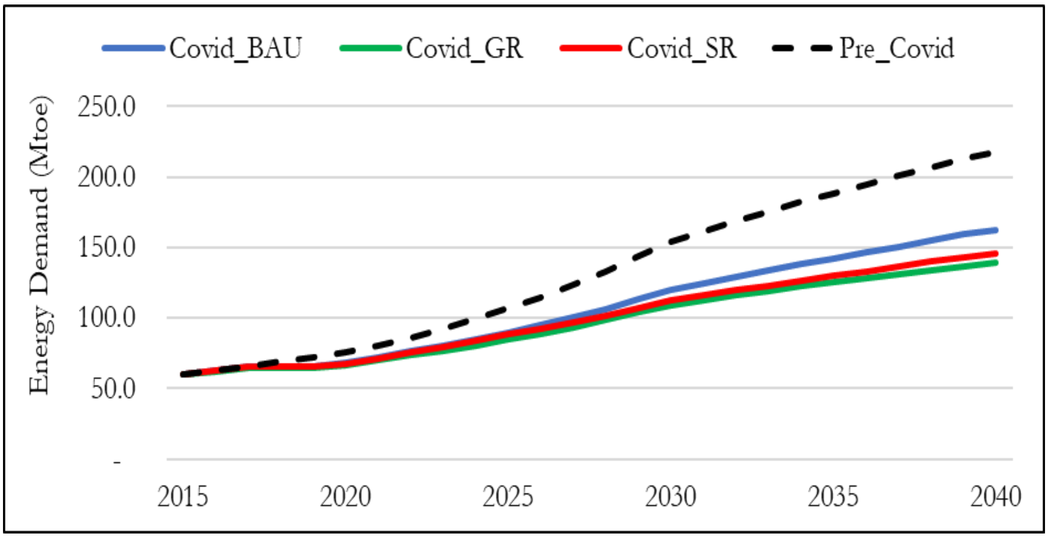

Fig 4 Impacts of COVID19 on energy demand under different scenarios

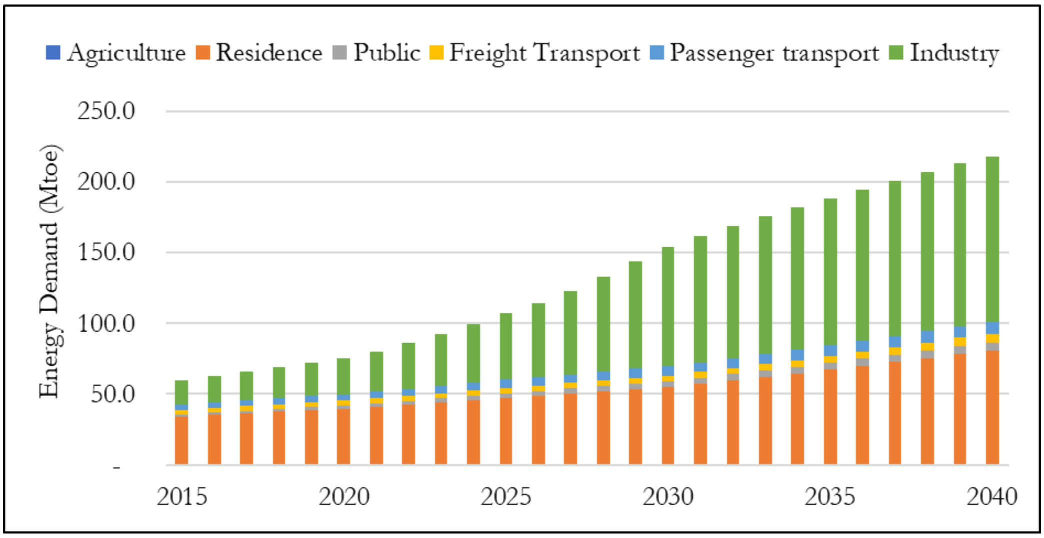

Fig 5 Increase in energy demand under CBU scenario

4.2. *Impacts on the Power Sector*

Power sector observed a different trend under each scenario. Given the imposed lockdown, there was decrease in electricity consumption from commercial sector and industrial sectors, while the consumption significantly increased in the residential sector. Figure 6 represents the increase in power demand under different scenarios. As compared to pre Covid scenario, the electricity demand in post Covid is expected to remain suppressed due to limited activities across all key sectors. The key drop is coming from the industrial sector which is directly linked with the GDP growth of the country. With a substantial loss to GDP during and post Covid, the productivity has dropped leading to drop in utility consumption.

The power consumption of Pakistan in PCS was estimated to increase from 112 TWh in 2020 to 717 TWh by 2040. In CBU, this demand is projected to increase to 414 TWh by 2040 which is almost 43% lower than the corresponding value of PCS. In a slow covid recovery, the total demand would further drop by 40 TWh by 2030 and 82 TWh by 2040. In relation to these scenarios, GRS depicts that the demand is progressing at a less rate and would reach 223 TWh by 2030 and 298 TWh by 2040. This depicts a power saving of 53 TWh by 2030 and 116 TWh by 2040. The difference resulting in these scenarios should is essential for policy making, as neglecting this could lead to idle capacity payments in the system.

4.3. *Power Generation Mix*

The generation mix of Pakistan is being driven by the existing policies operating under a demand-supply equilibrium. All post covid scenarios have followed the guidelines in IGCEP 2021. Both scenarios of fast and delayed recovery have the same percentage of the energy generating mix until 2040 since they are both driven by the same policy. However, because a gradual recovery scenario has a somewhat lower energy demand, the value produced by each source varies.

The power generation share by 2030 in SGS and CBU is mainly dominate by hydropower-47% and followed closely by Coal-21%, solar & wind-12%, and natural gas at just 3%. Use of residual furnace oil in the power sector is expected to be phased out by 2025. For green recovery scenario, the generation mix is depicted in Figure 7. After 2030, the green recovery scenario operates without any power sector constraints, and a comparatively larger intake of solar and wind has been depicted pertaining to their lower costs. As per the modelling results, the

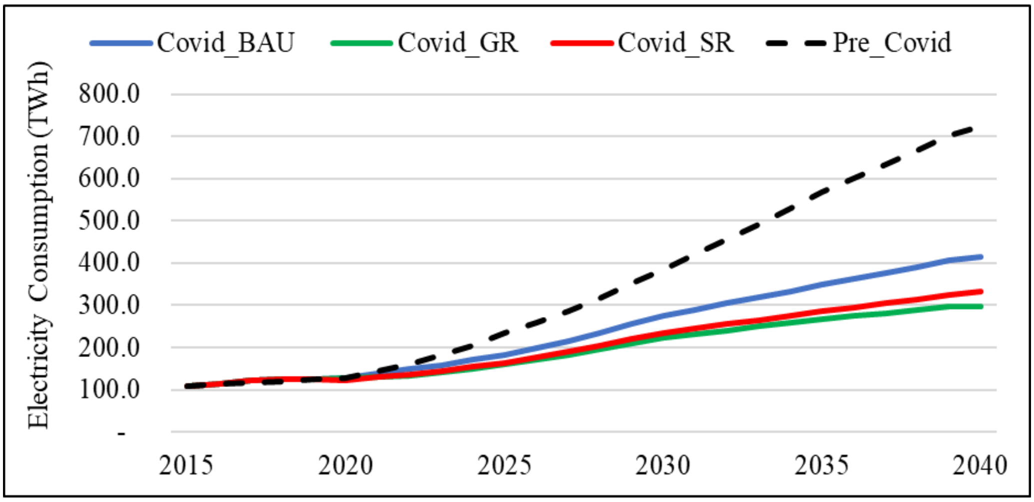

Fig 6 Impacts of COVID19 on electricity consumption under different scenarios

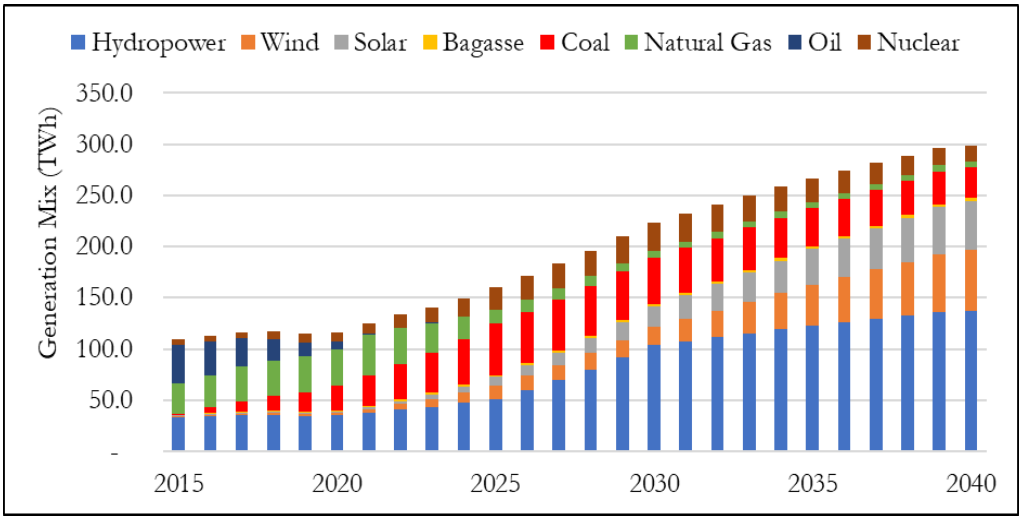

Fig 7 Pakistan's Power generation mix in the Green Recovery Scenario

share of VRE i.e., Solar and Wind will increase from 12% to 36% (i.e., 20% Wind and 16% Solar) by 2040 while the share of Coal would reach around 20% by 2030 and 10% by 2040.

Figure 7 further depicts that after 2030, the share of VRE would increase from 12% to 36% by 2040. Hydro would still constitute the larger share of almost 46% leading to a combined clean energy share of almost 80% by 2040. Hence, under a least cost scenario, clean energy is evidently a better economic and environmental case.

4.4. Environmental Profile of Pakistan's Energy Sector

A direct index is observed between the increase in energy demand and the consequent increase in overall emissions. Figure 8a represents the emission profile of Pakistan under different scenarios, while Figure 8b represents the emissions under different scenarios in CBU scenario.

According to Figure 8, the total emissions from the main demand sectors decreased by around 14.2 Mt of CO2 equivalent in 2020. In the PCS, it was anticipated that emissions would rise to about 256 Mt by 2030; however, in the CBU scenario, it is anticipated that overall emissions will decrease to 183 Mt in a quick recovery scenario, 168.5 Mt in a SRS, and CBU164 Mt in a GRS by 2030. The difference between the value in the GRS and the value in the scenario in 2030 is 19 Mt, or around 10.3%. Due to growing use of energy-efficient appliances and a change from conventional to modern energy consumption habits, this decrease may exceed 16% by the year 2040. The model only took into account the direct CO2 emissions from the power plants in the emissions from the power sector (shown in Figure 9). When the restrictions of the ARE policy are eliminated after 2030, the PCS predicts that a greater penetration of local coal-based power generation would result in higher emissions.

The PCS predicted that the emissions would surge from 50 Mt in 2019 to 88 Mt in 2030 and 338 Mt in 2040. In the case of Post COVID scenarios, it is anticipated that the emissions will increase from 50 Mt in 2019 to 53 Mt, 45 Mt, and 42 Mt by 2030 in the scenarios of a CBU, SRS, and GRS respectively. These values will be 79 Mt, 63 Mt, and 29 Mt, respectively, by 2040. It should be observed, nevertheless, that in every post-COVID scenario, a decline in emissions also corresponds to a fall in energy consumption. Since 82% of the generation share comes from renewable sources (including hydropower), which have zero direct emissions, the emissions by 2040 in a green recovery scenario are even lower than the current amount of emissions. Therefore, in a scenario of a green recovery, a greater proportion of renewable energy sources and energy-saving measures would be crucial in reducing emissions.

Further, many studies have highlighted that emission reductions from COVID must not be taken as a permanent

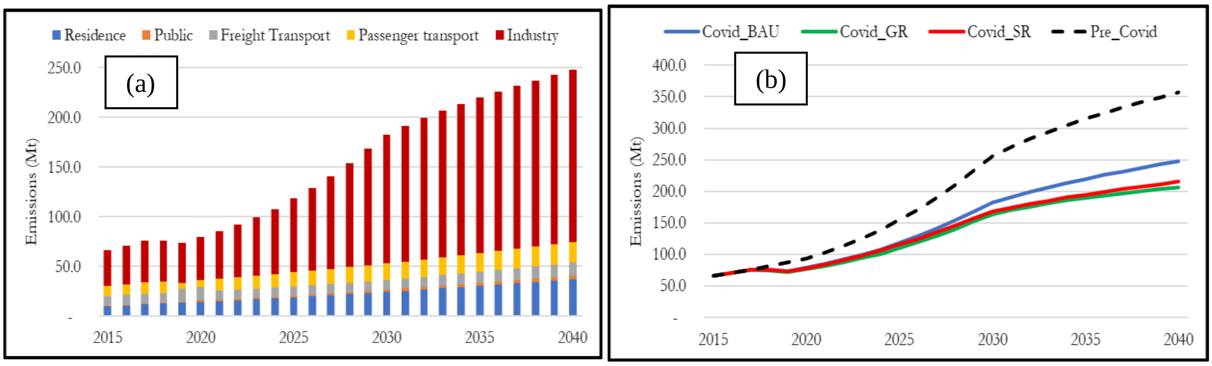

Fig 8 a) Emission from Energy Demand Sectors in CBU, b) Emission from Energy Demand Sectors under different scenarios.

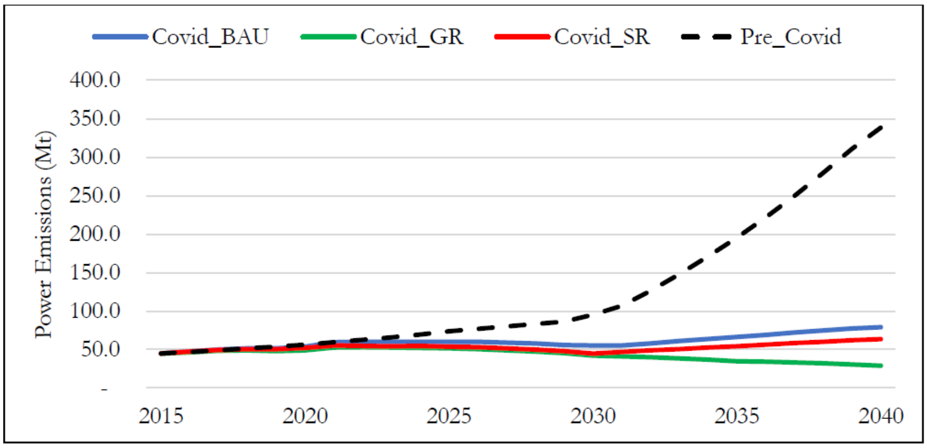

Fig 9 Carbon dioxide emissions from Pakistan's power sector in a Green Recovery Scenario

change and there are no signs that the impacts of climate change will be reduced. Giacomo Nicolini et al. (Nicolini *et al.*, 2022) indicated that after a brief fall brought on by the economic slowdown, carbon dioxide emissions are quickly returning to normal and are still far beyond reduction targets. Continued record high GHGs concentrations in the atmosphere expose the earth to severe future warming. Devastating extreme weather events are being fuelled by rising global temperatures, with escalating effects on economies and civilizations (Diaz-Camal *et al.*, 2022). The loss of work due to heat alone amounts to billions of hours. The last five years saw one of the highest average global temperatures ever. In the next five years, there is a rising possibility that temperatures will momentarily exceed the preindustrial barrier of 1.5° Celsius.

4.5. Power Sector Generation Costs (Levelized)

The potential and levelized cost of each source are taken into consideration when evaluating the investments for the power sector, and the levelized cost of energy is then used to compute the overall required investments for required energy mix. It should be highlighted, nevertheless, that the findings do not predict any future technological breakthroughs or reductions in technology costs. Each source's per-unit generation cost has been considered when evaluating investments in the energy sector. Additionally, as certain technologies are not available in Pakistan, some assumptions and values for such technologies are also derived from outside sources. Figure 10 represents the levelized cost of power sector under different scenarios.

Pakistan total cost of power generation in 2020 is around \$10 billion. In PCS, this was expected to increase to almost \$23 billion by 2030 and \$48 billion by 2040. However, given that the demand has been significantly suppressed in the post covid scenarios, the maximum generation cost is expected to increase to a maximum of \$17.3 billion by 2030 and \$26.4 billion by 2040. Apart from the generation cost, the net present value of Pakistan's power sector investments sum up to almost \$40 billion, ignoring the capacity payments of existing independent power producers. The overall cost of generation is constrained to \$13 billion in the GRS, showing that energy efficiency and conservation measures can result in annual savings of about \$3 billion. These savings have grown to \$9 billion in a single year by 2040. Figure 11 further illustrates the contribution of various sources to the total cost of power generation under the green recovery scenario.

Pakistan's electricity sector already has a limited capacity for evacuation and an excess of capacity. The unstable nature of Pakistan's current system makes it unable to manage intermittent renewable energy sources. Prioritized attention might be given to system stabilisation before the nation begins to deploy renewable energy sources. Decentralized energy systems could be used to prioritise localised systems for enhancing energy access. Both of the aforementioned transition strategies, though, call on contributions from the public and private sectors. This poses serious difficulties and expenses for achieving a green recovery. Energy efficiency improvements in high-demand industries necessitate considerable grid modernization investments.

4.6. Policy Recommendations and the Way Forward

Since Pakistan has been recovering from COVID and making plans to "build back better" its economy a coordinated effort to mitigate climate change is needed at the same level and

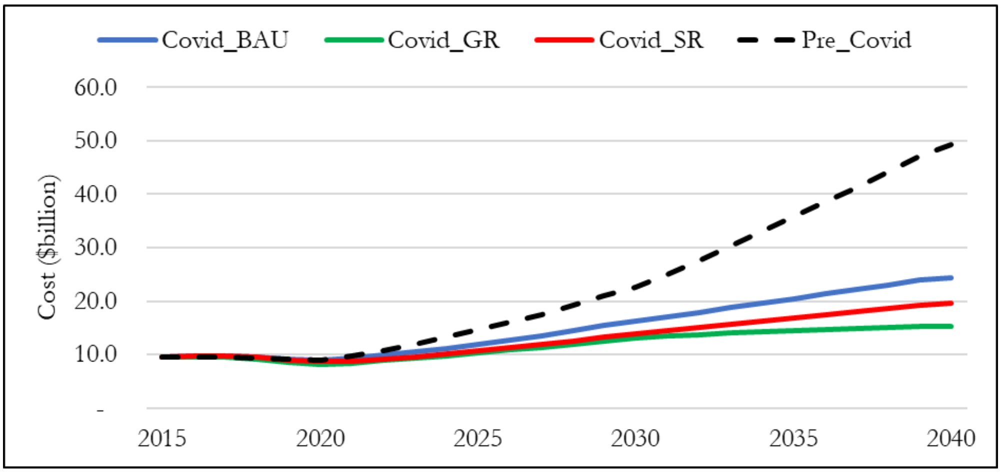

Fig 10 The levelized cost of Electricity of Power sector under different scenarios

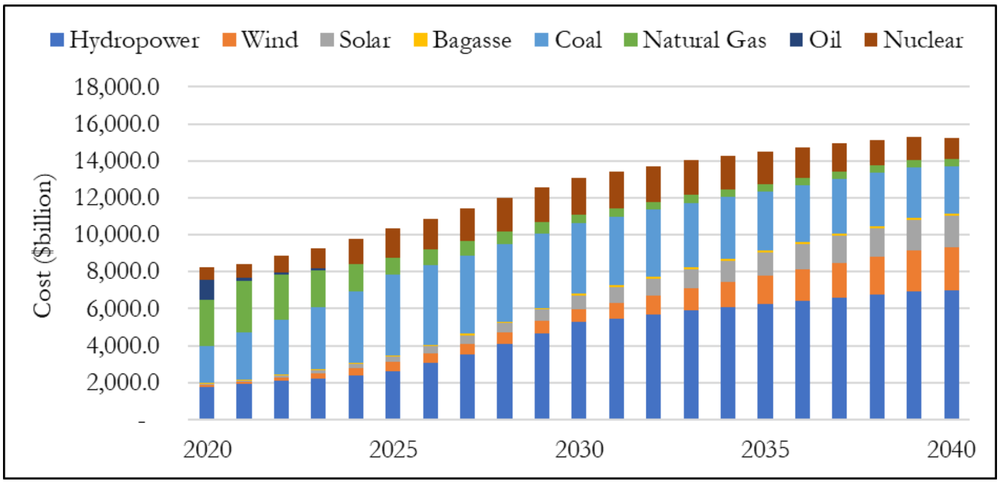

Fig 11 Share of different sources in total levelized cost under green recovery scenario

pace as COVID19 recovery, with more long-lasting and beneficial side effects: clean energy, clean air, green jobs, clean water, and more nature. The key recommendations are as follows:

- If Pakistan is to successfully combat the effects of climate change and maintain stable energy markets, renewable energy expenditures must triple by 2030 in the Post COVID recovery. Reducing spending in coal, oil, and gas while urgently increasing investments in large-scale RE sources will necessitate technical and policy solutions.
- The essential to having a strong engagement to climate action and the recognition of recent climatic disasters and global warming patterns is represented in Pakistan's revised Nationally Determined Contributions (NDCs), which include objectives and targets. Reiterating the promise to mobilise financial resources to reduce CO2 and non-CO_2 emissions like methane and hydrochlorofluorocarbons could result from an acknowledgment that inefficient fossil fuels and subsidies are in conflict with the Paris accord. A plan to lower methane emissions from coal mines would help cut emissions by reducing the demand for coal and increasing the use of clean energy alternatives.
- Prioritizing actions for a smooth transition and accounting for lost jobs present significant challenges. To increase its biodiversity and implement nature-based solutions like the Ten Billion Tsunami Tree Programme (TBTTP), Pakistan must expedite its actions.
- For under-resourced nations with constrained fiscal flexibility, like Pakistan, the availability of sustainable finance is crucial for fostering green recovery. Building strong ESG profiles to promote transparency, raise awareness, and strengthen investor and corporate sector commitments. Mobilizing private-sector investment through green bonds.
- The transfer and exchange of low-carbon technologies, environmental goods, green products, best practises, data sharing, and an increase in sustainable finance flow between developed and developing countries can support international cooperation given that environmental challenges are transitory in nature. Climate talks (like COP26) are crucial for advancing multilateral actions toward established environmental goals.
- Public-Private Partnerships (PPP) can be utilised for the adoption of building regulations, energy performance standards, and energy efficiency certificates while taking into account the financial and

environmental benefits of energy efficiency and conservation measures. Government-sponsored programmes can be initiated for energy upgrades for existing buildings as part of a "whole of economy" decarbonization strategy to combat emissions produced in the housing sector during production, construction, maintenance, and destruction.

- Effect on medical facilities COVID has emphasised the significance of expanding access to energy. The regulatory structures and business models in the energy sector need to be reviewed as part of the recovery process. Along with the adoption of the digital payment model, net metering, and investments in data collecting systems, decentralised and rooftop energy systems are also an option. Finding the energy subsidies that are inefficient, cause unfairness, and wasteful usage should be prioritised for reorganisation. Reforms to subsidies should be created so that they are more effectively aimed at the poor and less susceptible to price incentives.
- To reduce emissions, ensure sustainability, minimise waste and pollution, and improve resource efficiency and resource recovery, companies must adopt circular economy concepts.

5. Conclusion

COVID19 has posed a long-term economic downturn and socio-economic costs, particularly to the developing countries such as Pakistan. This however has also opened a window for some opportunities to recover the country in a more sustainable and resilient manner. It however goes with the evidence that a low carbon recovery is vital and is achievable. While there are many hurdles and challenges in this regard, the biggest for developing nations is the financing needs of green recovery. This study particularly addresses this challenge for the energy sector of Pakistan by modeling the impact and potential green recovery pathway from COVID19 using a LEAP model.

The results obtained from the model indicates that significant socio-economic benefits can be achieved by adopting a green recovery pathway, that essentially includes three key components i.e., i) transition to clean and green energy, ii) incorporating energy efficiency and conservation, and iii) decarbonization of the transport and industrial sector. The extent of the socio-economic benefits is however dependent on the pace of economic recovery as a delayed response has exponential socio-economic costs.

The GDP growth of Pakistan in the Post COVID scenarios is expected to be around 20% lower in the PCS by 2030, which depicts that to bring country back on track, economic stimulus of around $42 billion would be required by 2030. And, for a Green Recovery, Pakistan would require a total of $120 billion by 2030, accounting for increase in renewable energy power generation, energy efficiency, and improvement in Transmission & Distribution. The use of more efficient technologies, efficiency improvement in current technologies, green buildings, and increase in fuel efficiency, there is a potential for annual energy savings of around 10 Mtoe (or 9% by 2030). Energy efficiency measures can lower emissions by 16% by 2040 and save around $ 3 billion in a single year by 2030 and $9 billion by 2040. The model results also indicate that the combined share of solar and wind in total Levelized Cost by 2040 would be 26.5% which would be significantly lower than their power generation share of 36%, representing that further reliance on VRE could lead to economic savings in power generation.

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