Optimal Long-Term Power Sector Planning for Pakistan Through Modelling of Base and Alternate Scenarios

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Abstract

Background:
Engineers, planners and economists model electricity system to forecast the demand and energy mix scenarios on the basis of different factors including economic, environmental and other aspects. The present study specifically concentrates on long-term electrical power sector planning for Pakistan up to 2040 while considering the effect of economic, technical, political and social factors.

Methods:
In this research, Long-range Energy Alternative Planning system (LEAP®) software is used to determine future electrical power demand and generation plan. Three different models are developed to predict the electricity demand of Pakistan including empirical model, econometric model and ecometric model with linear regression. Generation plan is developed based on current government policies under baseline scenario. Baseline scenario has compared with alternate scenarios including delay in hydro, green energy source maximization and energy conservation for period from 2018-2040. Economic analysis has been performed by comparing different scenarios to investigate and quantify their economic benefits.

Results:
Electricity demand projected from the three models are found to be 470 TWh, 530 TWh and 230 TWh for 2040 which was 57.35 TWh in the base year 2004 and 94.47 TWh in 2017. Electricity generation projected for 2040 for Pakistan with econometric model with linear regression estimated to be 270 TWh which was 80.5 TWh in 2004 and 119.35 TWh in 2017. From the economic analysis, delay in hydro scenario was found to be the most expensive scenario with a total loss of 88 billion US dollars up to 2040. Green energy scenario and energy conservation scenario saves around 13 billion US dollar and 91 billion US dollar respectively. Cost based optimization scenario saves a huge cost of 461.7 billion US dollar compared to baseline scenario because of less running cost and negligible fuel import cost.

Conclusion:
The most suitable pathway for meeting the demand-supply gap of Pakistan is the energy conservation policy scenario in which generation plan target could be well achieved by targeting 20% energy conservation strategy by using energy efficient devices. Government should make an energy security plan to recognize the energy conservation policy to cater demand and supply deficit with sustained economic growth.

1. Introduction
Pakistan is a developing country with a total population of 207.77 million, annual Gross Domestic Products (GDP) growth rate 5.8% and inflation rate is 4.2% for the year 2017. The average per capita income is around $1641 and 63.62% of the population is living in rural area[1]. The population of the country is increasing with the growth rate of 2.4% and it is expected with the current growth rate, the country will become the 4th largest nation on earth by 2050[2]. The power consumption per capita of the country is only 500 kWh, which is quite low in comparison to world average per capita power consumption of 2603 kWh[3].

For power generation fossil fuels play a critical role as their availability and price fluctuation in international market affects power generation facilities[4]. Pakistan has large reserves of indigenous coal of over 186 billion tonnes. In addition to natural energy resources like coal and gas, country is also having a high potential for renewable energy resources including wind, solar, hydro, tidal and geo-thermal. However, still Pakistan is facing energy deficiency since last decade which is hampering the economy growth badly[5]. One of the major identified reasons of energy crisis is heavy reliance on imported fossil fuel as most of the electrical power is generated by conventional oil and gas-based power plants[6, 7].

The power shortages have become the prime economic concern, that the government take the challenge to prioritize the electricity generation. In 2013 government of Pakistan has developed National Power policy in order to support national needs of energy for current and future scenarios. In the first task, Government of Pakistan clears Rs. 480 billion payables of power sector entities against public sector utilities and IPPs. This eased load shedding and added 1700 MW electricity in the national grid. The second major step is to ensure financially stable power system with the provision of targeted subsidy to the consumers of power. Furthermore in 2015 the power generation policy was initiated by Government of Pakistan which motivated the local and international power investors to participate in the power projects development in Pakistan by offering them upgraded incentives and simplified processing[8].

Another major breakthrough by Government of Pakistan for the development of country’s energy sector was China-Pakistan Economic Corridor. Under this corridor power generation and transmission projects have been made possible with 35 billion US dollar expenditure which were to be implemented in IPP mode.

Indigenous resources of oil and natural gas in Pakistan are depleting and are not fulfilling the energy demands of the country. For this reason, government has built translational pipelines to import gas from Iran as well as focuses on indigenous production in the country. Similarly, crude oil caters only 15% of energy demand, while 85% has met from the crude oil and petroleum products imports[1]. In addition to this another challenge is harnessing of coal reserves from Thar and renewable resources which is a slow process due to lack of resources and financial issues. In summers,
due to extremely high demand overpriced generation makes electricity prices higher for all types of consumers. This hype in electricity caused increased dependence on fossil fuels and thermal sources. The use of these fuels exhausts greenhouse gases and air pollutants which is another constraint\[9\].

The role of electricity in everyday life has increasing rapidly and demands a reliable technique to forecast the demand logically. Various models for forecasting electricity demand provide that required technique. For better planning of utilisation of resources, expansion in capacity and extension of grid and network, long-term forecasting is a basic need. In Pakistan long-term electricity forecasting studies has done by National Transmission and Dispatch Company (NTDC). However, the expectations of mitigating the power crisis in the country has not been met by NTDC load forecasting studies due to some reasons \[9\].

For energy planning and strict target emissions, many advanced energy modelling software have been developed. In such softwares, future energy trends are modelled in order to better understand the impact of new technologies on changing fuel-mix scenarios, environment and existing infrastructure\[10, 11\]. These models have been utilized to predict the impact of forthcoming policies and decisions on existing power scenarios. Several countries have used such models in energy planning to select the most beneficial future path\[12, 13\].

Electricity analysts such as engineers, planners and economists manage and plan the electricity by using electricity system models in order to trade electricity and generation expansion planning. The electricity systems are modelled to guide the government and industries on the most economic and environmentally sound supply system of electricity\[14\]. The present study specifically concentrates on long-term electrical power sector planning for Pakistan up to 2040 while considering the effect of economic, technical, political and social factors. It forecasts the rise in electricity demand and plans for the supply side using Long-range Energy Alternative Planning system (LEAP)\[15\]. In this research, LEAP software is employed to determine future electrical power demand using three different models and generation trends under baseline scenario (BL) and to simulate other possible alternate scenarios \[13, 15\].

2. Overview Of Power Sector Of Pakistan

In Pakistan, power sector is distributed and operated by public-private partnership. These organizations are responsible for generation, transmission and distribution of electrical power to end consumers with appropriate tariff. Electrical power is being generated by Water and Power Development Authority (WAPDA), Generation Companies (GENCOS), Independent Power Producers (IPPs) and Karachi-Electric (K-Electric). For power dispatching, NTDC and Central Power Purchasing Agency (CPPA) are working under the supervision of National Electric Power Regulatory Authority (NEPRA). The task of power distribution to the consumers is fulfilled by ten Distribution Companies (DISCOs)\[9\].

All departments mentioned above are working under Ministry of Water and Power except K-Electric and IPPs. The institutional structure of power sector of Pakistan is shown in Figure 1. K-Electric is the only vertically integrated power utility which controls generation, transmission and distribution of energy to the consumers of Karachi. It meets its overall electricity demand from its own generation units with an installed capacity of 2,267 MW and imports from IPPs, WAPDA and Karachi Nuclear Power Plant (KANUP) \[8\]. Currently there are 20 private power companies operating in Pakistan and contributing their share of electricity to the national grid to meet the demand\[5\].

Maximum Electricity demand in Pakistan for the year 2016-2017 is 24,290 MW for PEPCO area and 3,270 MW for KEL area. It has been noticed that electricity demand increases by about 6% to 8% annually during the last five years\[4\]. According to NTDC regression analysis done in 2008 the electricity demand will increase by a ratio of 8% annually between year 2008 to 2030\[16\]. In Pakistan, electricity consumers are categorized as domestic, industrial, agriculture, commercial and others (electric traction, bulk lightening). Domestic sector consumes the major part of electricity followed by industrial sector as shown in Figure 2.

The total installed generation capacity of Pakistan on 30th June 2017 was 28,399 MW, out of which 26,186 MW is connected to NTDC system whereas 2,213 MW is connected to K-Electric Limited system. This capacity reached to 29,673 MW till Feb 2018. Total electricity generated by power plants is 120,621GWh during FY 2016-17 which is increased compared to 114,093GWh for FY 2015-16 \[4\].

In Pakistan electricity is mainly produced by fossil fuels i.e. coal, oil and gas, hydro, nuclear and renewables (wind, solar and bagasse). The share of different fuels in electricity generation from the FY 2012-13 to FY 2016-2017 is shown in Figure 3. It is evident that share of hydro-electricity has been decreased over the last four years and dependence on fossil fuel is approximately same. On the other side, the country has an abundant renewable energy resource. However, only hyroelectric power is exploited among all options. Other renewable resources e.g. PV panels, wind energy and bagasse have so far contributed 2.46% in generation\[17\].

Currently, nation is facing an increasing demand and supply gap in electrical power sector as shown in Figure 4. In 2017 demand deficit was 6328 MW. The major reasons for electrical power deficit in the country are identified as delay in installation of new power plants and reliance on costly imported fossil fuels\[4\]. Announced or unannounced 8 to 10 hours daily load-shedding was common for all consumer categories. This power crisis has damaged the country's economy and GDP growth. Moreover, the expenses of backup power generators and costly fuel for them put an extra burden on weak economy\[18\].

3. Energy Modelling Tools And Techniques
Energy modelling is adopted to express complex systems in understandable form and to capture its behaviour under given conditions \[19, \ 20\]. Generally energy models can be classified based on an analytical approach (i.e. top-down and bottom-up), purpose of the analysis (i.e. forecasting, exploring or scenarios analysis), the data requirements (i.e. qualitative and quantitative, desegregate and aggregate), the time horizon (i.e. short, medium, and long term), the underlying methodology (i.e. econometrics, macro-economics, economic equilibrium, simulation, optimisation, spreadsheet, and multi-criteria methodologies), the mathematical approach (i.e. linear programming, mixed integer programming, and dynamic programming), and the geographical coverage (i.e. local, national, regional, and global) \[21\].

The existing framework of energy models is different having own techniques and solutions\[11\]. Several simulation tools have been developed to model energy planning including LEAP, MARKAL/TIMES (Market Allocation), ENPEP (Energy and Power Evaluation plan), MESSAGE (Measure Energy Supply Strategy Alternatives and their General Environmental Impact) and Energy PLAN to track energy demand and generation \[22, \ 23\]. These tools have been used increasingly to provide insights into how energy systems can evolve in the future. Industrialised countries used these models to analyse energy demand, energy system planning and for policy making\[21\]. Some of the researches done in the different countries in the past years for energy modelling using different tools and methodologies are presented in Table 1.

Table 1 Summary of researches done using energy modelling tools around the world \[24-31\]

| Year | Research title                                                                 | Energy modelling tools and methodology                                      |
|------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| 2004 | Long-Term GHG Emissions Outlook for Greece                                    | Nonlinear, equilibrium ENPEP-BALANCE model                                 |
| 2010 | Formulating an optimal long-term energy supply strategy for Syria using MESSAGE model | Long-term optimal plan using MESSAGE model                                 |
| 2013 | Integrating renewable energy with flexible storage systems: A case study of GB and Greece | National level scenario based EnergyPLAN model                             |
| 2014 | A Canadian 2050 energy outlook: Analysis with the multi-regional model TIMES-Canada | Long-term multi-region model with TIMES optimisation modelling framework   |
| 2014 | Developing a Model of the Irish Energy-System                                 | EnergyPLAN model using technical optimisation                             |
| 2015 | Future scenarios and trends in energy generation in brazil: supply and demand and mitigation forecasts | Scenario based LEAP model                                                  |
| 2016 | Modelling building's decarbonization with application of China TIMES model    | Long-term multi-region model with TIMES                                    |
| 2017 | A review of China's energy consumption structure and outlook based on a long-range energy alternatives modeling tool | Long-term bottom-up accounting framework LEAP model                        |

For electricity forecasting of Pakistan various models with different methodologies has been presented at national level in past few years by both Government and academic researchers. Government level studies at national level is given in Table 2\[32\]. The forecast methodology of these studies was based on mathematical or statistical methods with limited application of energy modelling tools.

LEAP in contrast to other tools has low data requirements and widely used software package, providing accounting and scenario-based modelling tool for physical energy and ecological policies\[33, \ 34\]. Substantial work has been done by some academic researchers on energy system of Pakistan using LEAP. M. Aslam Uqaili \[35\] have forecasted Pakistan’s electricity demand for study period of 2013-2035. Perwez, Sohail \[7\] have forecasted the electricity demand which is estimated to be 1312 TWh in 2030. Ishaque \[36\] have forecasted the electricity demand for 2014-2035 with three scenarios which is 303.7 TWh.

Table 2 Government level studies for analysing the energy system expansion in Pakistan\[9\]
4. Leap Energy Model For Pakistan

Pakistan's LEAP model is used to analyse the supply policy selections and demand assumptions for future power generation system on the basis of economics, technicality and implicit environmental implications.

In this study, top down approach has been chosen for the demand projection. On the supply side, LEAP provides a range of accounting and simulation methodologies for modelling electricity generation and capacity expansion planning[33]. The scenarios would require data for bottom-up approach regarding to electricity generation technologies comprising installed capacity, percentage availability, efficiency, all involved costs, emissions related to fuel, etc[37].

Collection of authentic data is a difficult process in electricity modelling for developing countries. In LEAP model of Pakistan, 2004 is taken as base year and historical data is entered from 2004 to 2017. First scenario year for which the expressions are entered is 2018 to predict the future electricity consumption till 2040. The data sets in LEAP consists of various modules such as key assumptions, demand, transformation and resources. The data sets for various modules are shown in Figure 5 [37] below:

4.1 Input Parameters in Leap Model

Historical data from the year 2004 to 2017 entered for different parameters described in above section and is taken from multiple authentic sources. These sources include Pakistan Economic Survey 2017-2018[1], NEPRA State of Industry Report (2009-2017)[17, 38, 39] and cost data sources include Upfront tariff by NEPRA[40-42] and PAK-IEM Model Design Report[43]. The system load duration curve for the year 2016-17 of electricity sector of Pakistan is shown in Figure 6 given by NTDC Power Data Reference Book 2017[44]. This load duration curve is expressed in percentage of peak demand describes peak power requirements variation from the highest to the lowest load. This curve is required in LEAP when dispatch rule is set as Merit order. When dispatch rule is set to optimise method then energy load shape required in LEAP. Daily load curve for Pakistan in the year 2017 is shown in Figure 7. In this section the data of input parameters has given in appendix (Table A-1 to Table A-7) for modelling of Electricity sector of Pakistan.

4.2 Limitations in The Leap Model

LEAP energy model of Pakistan used in this paper has several framework limitations and data constraints listed below:

i. Transmission network capacity constraints are not considered in this model.

ii. Hourly load profiles are not considered in the model, rather calculations are done on annual generation load curves. Due to this limitation there is no effect on the choice of base load and peaking capacity which are based on hourly or seasonal load patterns[21].

iii. The model is limited to renewable energy solutions as there is no correlation of weather patterns impacts on hydro, wind and solar technologies[7].

iv. Import electricity from Iran which is 496 GWh and share of 0.41 % is not considered in this model[4].

These limitations can be overcome if authentic data would be available. In the next section electricity demand is projected by three different models.

5. Demand Projections
Energy demand is increasing across the globe due to rise in population, income and industrialization. This situation directs towards the need of accurate forecasting for energy system planning. In Pakistan, electricity demand is increasing with an overall growth rate of 8%[45].

Recently in Pakistan, electricity demand has been forecasted by NTDC through multiple linear regression analysis under three scenarios. These scenarios include low, medium and high GDP growth rates of the country[46]. It has been found in the study that the main driver in electricity forecasting is possible increment in financial activities and economic growth which is reflected through GDP rate of the country[47]. From Pakistan Economic survey 2017-18 the GDP is 5.4% in year 2017[1]. However the expected average annual GDP growth rates till 2030 are 4.8%, 5.9% and 6.5% for low, medium and high GDP scenarios. Unfortunately, since last few years, the country has seen a sharp decline in the GDP growth, it is expected that either low or medium GDP growth rate is likely to be followed for demand projections in future[48]. Three models are developed in LEAP using different approaches for the future projections of electricity demand for all the sectors of Pakistan.

5.1 Empirical model

This model is based on the observations of electricity demand estimated by "NTDC Electricity Demand forecast based on multiple regression analysis Report" 2011. This report predicted the demand for 2035[16]. This method is simple and no historical data of demographic or economic variable are required. Table 3 represents the future prediction assumptions for the baseline scenario.

Table 3 Future assumptions till the year 2030 [4, 16, 49]

| Parameters                     | Future assumptions for the year 2040 |
|-------------------------------|--------------------------------------|
| Total energy of demand sectors|                                      |
| Agriculture                   | Domestic Growth rate                 |
| Industrial                    | 6.2 %                                |
| Commercial                    | 6.72 %                               |
| Others                        | 12 %                                 |
| Others                        | 9.59 %                               |
| Others                        | 9 %                                  |
| Transmission and distribution losses | 14.9 %                             |

5.2 Econometric model

This model is a statistical model which predicts the electricity demand using economic variables. This model requires historical data of population, total number of electric consumers in each sector and GDP of each sector. Baseline scenario is established by utilizing the estimated growth rates of economic variables from NTDC Electricity Demand forecast based on multiple regression analysis Report 2011. This report projected population and GDP growth rates for different sectors of the country by regression studies.

Demand analysis in LEAP is an end-use based approach where any economic or demographic indicator can be applied for constructing alternate scenarios which examine how total consumption in all sectors evolve over time. In LEAP the electricity demand is calculated by the formula given in equation 1.

\[ D_{b,s,t} = T A_{b,s,t} \times E I_{b,s,t} \quad \text{(Eqn. 1)} \]

Where D is energy demand, TA is total activity, EI is energy intensity, b is the branch, s is scenario and t is year. Activity level represents the measure of social or economic activity for which the energy is measured. Final energy intensity is the final energy consumption in a sector per unit of activity level. In this model total number of electric consumers in each sector are taken as activity level and electricity consumption per customer is taken as final energy intensity in kWh unit. Future prediction assumptions for this model is given in Table 4.

Table 4 Future assumptions for econometric model
5.3 Econometric model with linear regression

A simple linear regression model is developed separately to predict the growth in population and GDP from 2018 to year 2040 as there is no built-in function in LEAP to perform regression analysis. Reliable historical data of population and GDP has been collected from Pakistan Bureau of Statistics[50] for the last 18 years as used in above model. Simple linear regression is performed by using equation 2 and the results presented in Table 5 are substituted in LEAP to predict the future electricity demand.

\[ Y = B + XT \]  

(Eqn. 2)

Where Y is a dependent variable (here population and GDP), B is an intercept, X is the slope, T is time interval.

**Table 5 Future projections with simple linear regression**
| Years | Population (Million) | GDP (Rs. Million) | GDP Agriculture | GDP Industry | GDP Services |
|-------|----------------------|-------------------|-----------------|-------------|--------------|
| 2018  | 208.3                | 12392633          | 2336771         | 2591336     | 7464526      |
| 2019  | 212.6                | 12235800          | 2367526         | 2529607     | 738667       |
| 2020  | 216.9                | 12595457          | 2413245         | 2600127     | 7582085      |
| 2021  | 221.2                | 12955114          | 2561245         | 2639607     | 7825502      |
| 2022  | 225.5                | 13314770          | 2504685         | 2741166     | 8068919      |
| 2023  | 229.8                | 13674427          | 2550404         | 2811686     | 8312337      |
| 2024  | 234.1                | 14034084          | 2596124         | 2882206     | 8555754      |
| 2025  | 238.4                | 14393740          | 2641843         | 2952726     | 8799171      |
| 2026  | 242.7                | 14753397          | 2687563         | 3023246     | 9042589      |
| 2027  | 247.0                | 15113054          | 2733282         | 3093765     | 9286006      |
| 2028  | 251.3                | 15472711          | 2779002         | 3164285     | 9529423      |
| 2029  | 255.6                | 15832367          | 2824722         | 3234805     | 9772841      |
| 2030  | 259.9                | 16192024          | 2870441         | 3305325     | 10012585     |
| 2031  | 264.2                | 16551681          | 2916161         | 3375845     | 10259675     |
| 2032  | 268.5                | 16911337          | 2961880         | 3446364     | 10503093     |
| 2033  | 272.8                | 17270994          | 3007600         | 3516884     | 10746510     |
| 2034  | 277.2                | 17630651          | 3053319         | 3587404     | 10989928     |
| 2035  | 281.5                | 17990307          | 3099039         | 3657924     | 11233345     |
| 2036  | 285.8                | 18349964          | 3144759         | 3728443     | 11476762     |
| 2037  | 290.1                | 18709621          | 3190478         | 3798963     | 11720180     |
| 2038  | 294.4                | 19069278          | 3236198         | 3869483     | 11963597     |
| 2039  | 298.7                | 19428934          | 3281917         | 3940003     | 12207014     |
| 2040  | 303.0                | 19788591          | 3327637         | 4010523     | 12450432     |

6. Modelling Of Different Energy Scenarios Of Pakistan In Leap Software

LEAP is a scenario-based modelling tool in which scenarios represents storylines of how an energy system might evolve over time. For Pakistan LEAP energy model four scenarios were developed in this study included Baseline scenario, Optimization scenario, Delay in Hydro, Green Energy and Energy Conservation scenario. Description of each scenario have been discussed in the next section.

6.1 Baseline (BL) Scenario

The baseline scenario will maintain the most expected growth planned by government for different electricity consumption sectors[22]. This scenario portrays the current trends in electricity sector and forecasting demand and supply after considering the sequence of installation of power plants as planned by the government. The BL or business-as-usual scenario in LEAP reflects the most likely development of power system in which supply and demand policies will continue in the future as they were in the past without considering any new policy implication[23]. This scenario is implemented by the demand projections by NTDC Electricity Demand forecasting Report 2011[16] and generation capacity additions for future by NEPRA State of Industry Report 2016-17[4].

6.1.1 Generation Plan

Pakistan has an immense potential of renewable energy resources and has indigenous coal reserves. The anticipated indigenous coal reserves can produce 100,000 MW for next 30 years. Also, the total hydro potential is more than 40,000 MW from which 24,000 MW of electricity could be generated[51]. The other renewable resources including wind, solar and biomass are also prominent with respect to their potential. In case of solar,
Pakistan receives 7.6 hours average sunlight daily for approximately 300 days in a year in almost all parts of the country. Such a huge solar potential is enabling to produce an average 5-7 kWh/m$^2$/day. Moreover, the total estimated potential of wind and solar energy resources is 50,000 MW and 70,000 MW[52].

In order to meet the demand projected in above section the model calculated the capacity expansion according to merit order of each process provided. For Pakistan NTDC and NEPRA State of Industry report 2016-17 predicted the power plant additions by the year 2021 and 2025 as shown in Table 6. The capacity additions for the year 2040 are gathered from PAK-IEM policy analysis report.

**Table 6 Expected power plant capacities up to 2040[4]**

| Fuel                  | Capacity for the year 2021 (MW) | Capacity for the year 2025 (MW) | Capacity for the year 2040 (MW) |
|-----------------------|---------------------------------|---------------------------------|---------------------------------|
| Gas/RLNG             | 12,626                          | 12,626                          | 3,000                           |
| Oil                  | 6785                            | 6785                            | 3,000                           |
| Coal                 | 8,232                           | 12,163                          | 39,000                          |
| Hydro                | 10,244                          | 12,676                          | 28,000                          |
| Nuclear              | 2,582                           | 4,782                           | 5,000                           |
| Renewable (Wind/Solar / Bagasse) | 5,153                           | 5,153                           | 5,900                           |

These power plant additions are based on National Power Policy 2013 [53] which focused on cheaper fuels by reducing the basket price and addition of affordable and sustainable power generation to the grid along with imported fuel dependency reduction. Oil based power plants for this reason declines in capacity from 25.91 % in fiscal year 2016-17 to 10.91 % in the fiscal year 2024-25. For fulfilling these objectives, indigenous coal through Thar mining, imported coal, LNG based power plants, nuclear, solar and wind power are to be added in future. Gas/RLNG has increased from 9000 MW to 12,626 MW as furnace oil sharply come down. Capacity of coal has increased from 3.09 % in the fiscal year 2016-17 to 19.56 % in fiscal year 2024-25 as the federal government has decided to put a cap on the power generation plants based on Thar coal [4]. The Federal Government also took steps in construction of large and small hydropower projects through public-private partnership [38]. The generation plan to meet the expected demand for the study period (2018-2040) is realized in the baseline scenario through LEAP model for future power generation. The data presented in Table 5 is entered in LEAP by using interpolation function. The value of electricity generation for each year is calculated by equation 3[29].

$$\text{Value}_{iz} = \text{Value}_{fy} + \left(\text{Value}_{ey} - \text{Value}_{fy}\right) \times \frac{\text{Year}_{iz} - \text{Year}_{fy}}{\text{Year}_{ey} - \text{Year}_{fy}} \quad \text{(Eqn. 3)}$$

Where $iz$ is an intermediate period (the value of which is to be interpolated), $fy$ is the first period used as a basis for interpolation, $ey$ is the end period used as a basis for interpolation.

### 6.2 Optimization Scenario (OP)

This scenario uses linear programming optimisation tool i.e. Open Source Modelling System, a built-in feature of LEAP software to optimize the cost. Authors have used this feature for optimal dispatch with different constraints [54]. In this paper, cost-based optimization scenario calculations were executed up to 2040 to generate an energy system with the lowest total net present value of the system over the entire period of calculation. In this scenario, generation cost will be optimized considering the existing generation plan and cost. Those plants having least variable charges will be selected as a base plant. Daily load data of Pakistan from 1$^{st}$ January 2017 to 31$^{st}$ December 2017[44] is imported in LEAP to create energy load shape required for optimization. Capital cost, fixed and variable operation and maintenance cost, fuel costs, process efficiency and maximum availability values has incorporated from Table A-7.

### 6.3 Alternate Policy Scenarios

Pakistan is a rich country with natural resources of hydro, wind, solar, tidal, coal and natural gas. The proper utilization of hydro, coal and other renewable resources would help the country to meet its future energy requirements. At present, the real energy security issues are not the availability of natural resources but the lack of investment due to unstable political conditions on the local or regional level[47]. Energy security of Pakistan is also governed by the global and regional geopolitical issues because of country geographical location[5]. The country natural gas reserves are also depleting and neighbouring countries, India and Pakistan are working on a gas pipeline plan to import natural gas from Central Asia and Middle East. The success of this venture essentially relies on future relation between the two countries[55]. The relationship of the country with USA, India, Europe,
China and another Muslim World has already played an important role in Asia. Moreover, in order to fulfil new generation plans, an enormous amount of local and foreign investment would be required. Direct foreign investment generally requires strong political base with stable law and order situation, economic strength through government policies, infrastructure, quality of labour force, quality of life and welcoming attitude[56]. The most probable outcome of any of the indicated hurdles would be delay in new installations and this will worsen the demand and supply condition[57]. Due to various factors of financial, technical and physical limitations the power projects may not come in stream as per announced schedule. Also, existing power system is unable to cope with the power generated due to inadequate upgrading and poor repair and maintenance of transmission lines, cables and transformer parts [58]. In regard to these situations three policy scenarios were considered for the comparison with Baseline scenario. These scenarios are discussed separately under next section.

6.3.1 Delay in Hydro (DH)

National and governmental stability plays an important role in implementation of power policy. Provincial disagreements on the issue of water have led to an insufficient power generation capacity in the country. Due to political issues, hydroelectric power development is one of the most delayed and controversial power projects. The major pending hydro project is Kalabagh Dam which was designed to replace the Tarbela and Mangala Dams[59]. Kalabagh dam have a high potential for power generation but it is now a three-decade delayed project. Kalabagh, Akhori and Bhasha dams could increase power generation and power water storage capacity by 23% of the country. Kalabagh, Basha dams and Mohmand dams power generation capacity and delay information are presented in Table 7. The historical delay of these plants are mostly due to the political situations, apprehensions and lack of knowledge[60]. By using interpolation method in LEAP as discussed in previous section the following assumptions of capacity addition and subtraction are implemented to realize this scenario.

i. 5,300 MW capacity of hydro power plants is eliminated from 10,244 MW in the year 2025.
ii. 8,100 MW capacity of hydro power plants is eliminated from 12,262 MW in the year 2025.
iii. Nuclear power plants capacity will be increased to 8,800 MW in 2030.

Table 7 Summary of delayed hydro power projects[61, 62]

| Dams             | Capacity | Commencement date | Completion date | Present status             |
|------------------|----------|-------------------|-----------------|----------------------------|
| Mohmand dam      | 800 MW   | June, 2012        | 31.Oct.2017     | Physical progress 99%      |
|                  |          |                   |                 | Financial progress 90 %    |
| Diamer Basha dam | 4500 MW  | July, 2009        | June, 2020      | Preliminary work is in progress. |
| Kalabagh dam     | 3600 MW  | Not constructed yet due to political issues of the country. |

6.3.2 Green Energy (GE)

This energy scenario is inspired by the induction of renewables based on Go Green initiative policies. Pakistan has an abundant natural renewable energy resource including hydro, solar, wind, biomass and others. However, the country has mainly focussed on hydro projects, the other renewable resources including solar and wind are not explored up to the expectation for commercial power generation. Green energy scenario focuses on promotion of renewable energy resources (wind, solar and bagasse) and small hydro plants will be added in existing hydro power plants capacity to understand its effect on the energy model. Alternate Energy Development Board has targeted that at least 5% to 10 % electricity generation will be based on renewables which is currently 2.46 % as seen in baseline plan[63]. It was also targeted in medium term development framework (MTDF) by government that 9,700 MW shall be generated through alternate resources by the year 2030[64]. Alternate Energy Development Board made a long term plan which is used for developing this scenario in LEAP with the following technologies listed below[63, 65]:

i. Wind power plants will attain the capacity of 6000 MW by 2030.
ii. Development of solar on-grid projects will be added 4500 MW by 2030.
iii. Capacity of bagasse plants will be 2000 MW by 2030.
iv. Small hydro plants would be added up to 1200 MW by 2030.

6.3.3 Energy Conservation (EC)

Energy conservation or efficient use of energy resources has been implemented to cater energy deficit which is cost-effective and environmentally feasible. This policy scenario is based on National Energy Conservation Policy prepared by National Energy Conservation Centre. This policy emphasizes on end-use efficient devices for various energy consumptions sectors. Its implementation is under consideration which promises 20% to
25% reduction in total energy consumption[66]. In this scenario, an energy model is built with respect to the 20% decrement in electricity demand in comparison to baseline scenario. This scenario will be the part of Demand side management which targets to reduce the current demand through using of more efficient equipment and energy saving measures thus reduces the power generation. This strategy also helps in saving the initial and running cost of new power plants [67]. A growth function is used in LEAP for implementation of 20% reduction in overall demand sector.

7. Results And Discussion

The possible effects of the above four scenarios on future generation plan and economy are discussed in this section. The results of each scenario are also compared with baseline scenario.

7.1 Forecasted Electricity Demand

Demand is projected for Pakistan up to 2040 for all the three models with three different approaches. Demand projections from each model in different sectors has been shown in Figure 8, 9 and 10. It is evident from figures that in empirical and econometric model the demand reaches to 470 TWh and 530 TWh in 2040 whereas in econometric model with linear regression demand projection in 2040 will be 230 TWh which was 94.47 TWh in 2017. Demand projections estimated in empirical and econometric models were based on NTDC regression studies outcomes, therefore their results are comparable. The demand prediction estimated in econometric model with linear regression was based on linear regression studies showing a linear demand trend up to 2040 therefore this model has been considered for further analysis in this study.

7.2 Electricity generation Plan Under Different Scenarios

In order to meet the demand predicted in above section the generation plan for 2018-2040 for econometric model with linear regression model has been projected. Generation plan for Baseline scenario is shown in Figure 11 and for Optimization scenario it is shown in Figure 12.

From Figure 11, it could be noticed that the percentages of hydro and coal resources are expected to increase significantly. By the end of 2017, most of the planned power plants will be thermal power plants running on oil and gas. Hydro and coal-based power plants are added in the long term with the prominent share of nuclear after 2028. It could also be noticed that in future, power generation would be highly dependent on the timely inclusion of coal and hydro projects. Their unavailability could create severe problems including starting of short-term expensive power projects or further widening the demand supply gap.

Generation plan with optimization scenario has been predicted by LEAP itself. For base load period LEAP favour those power plants which are capital intensive and have low running costs and for peak power requirements it favours those plants which are cheap to build but expensive to operate. For Pakistan, hydroelectric power plants have highest capital costs and low running charges and natural gas power plants have less capital cost and high running charges. For 2040 LEAP optimizes these two plants. Hourly load data is not available for Pakistan therefore peak demand has not been considered accurately by LEAP optimization, therefore natural gas share is almost negligible showing that optimization results are not appropriate to consider.

Baseline scenario is compared to alternate policy scenarios shown in Figure 13. It can be clearly observed that in DH scenario the generation from coal, oil, gas and nuclear increases as delay in hydro power plants would leads to over dependency on these fuels. On the other side, 10% inclusion of renewable energy resources under GE scenario would not change the other fuels contribution to some considerable extent. However, only 20% total savings in power sector under EC scenario could be one of the most effective ways to achieve the supply targets. In addition to reduce power generation requirement, EC implementation will also result in delaying the investment in power generation.

7.3 Electricity Generation Mix of Different Scenario for 2040

Electricity generation mix for the year 2040 is shown in Figure 14. In Baseline scenario coal and hydro electricity mix increases significantly and becomes 47% and 37% whereas oil and natural gas share reduces to 3%. For DH scenario share of thermal sources inreases to a considerable extent to 65.6% with decrease in hydro share to 8.1%. GE scenario raised the renewable share to 13% with less fossil fuel share compared to Baseline. EC scenario has the same generation fuel mix as of baseline because there is reduction in overall generation equally with the reduction in demand. For optimization scenario only hydro power plants contributed to almost 99.98% whereas only 0.02% from natural gas in electricity mix.

7.4 Economic Analysis

The factors which effect the power system economics are electricity prices, the capital cost, fixed and variable operation and maintenance cost, fuel costs and other monetary factors. For present case study, the necessary factors for cost-analysis of Pakistan are given in Table A-7 of Appendix. By incorporating the values mentioned in Table A-7 for each technology, cost analysis for each generation scenario is performed. Economic analysis of
baseline and alternate scenarios is performed by using the option of cost and benefit analysis in LEAP modelling software. The results for comparative cost analysis of baseline and different generation plans with optimized generation plan are shown in Figure 15.

Other factors include process efficiency, lifetime of plants and maximum availability. Maximum availability which is basically capacity factor shows maximum percentage of hours that the process is available. These factors affect all the cost parameters depending upon the type of plant. From Figure 15, it is clear that baseline scenario is one of the moderate cost scenarios with 34 billion US dollars in 2040. However, if the installation of hydro projects will not be completed in the time frame of 2018 to 2040, it will lead to a loss of around 1.74 to 6 billion US dollars per year which sums to 88 billion US dollars. This major difference in cost is due to increased share of gas and oil whose less maximum availability increases fuel costs. Cumulative social costs for each scenario in billion US dollars is presented in Table 8.

Table 8 Cumulative social costs up to 2040

| Cost Categories | Baseline Scenario | Delay in Hydro | Energy Conservation | Green Energy | Optimization Scenario |
|-----------------|-------------------|----------------|--------------------|--------------|-----------------------|
| Capital cost    | 174.24            | 147.58         | 133.21             | 186.25       | 158.90                |
| Fixed O&M cost  | 60.96             | 57.29          | 50.61              | 66.22        | 32.09                 |
| Variable O&M cost| 21.76            | 24.49          | 20.43              | 21.06        | 16.50                 |
| Fuel Production | 283.47            | 334.27         | 261.57             | 279.28       | 66.94                 |
| Fuel Imports    | 360.04            | 425.10         | 343.99             | 335.06       | 164.37                |
| Total           | 900.46            | 988.72         | 809.82             | 887.86       | 438.80                |

The policy of high renewable content in energy supply mix appears to be cost effective and reaches to 32.96 billion US dollars because of less variable charges, no fuel charges (for wind and solar) and highly efficient as compared to other fossil fuel-based plants. But it is the most expensive scenario in terms of capital cost. Green energy scenario could save 0.2 to 1.12 billion US dollars every year and saves a total of 25 billion US dollars from import of fossil fuel as shown in Table 8.

On the other hand, the policy of energy conservation under EC scenario will provide the savings of 0.05 to 3 billion US dollars per year with cumulative savings of 91 billion dollars by reduction in installation of new power plants. Here policy makers could also estimate the cost of energy efficiency and part of these savings could be invested for energy efficient machines in domestic, commercial and industrial sectors. Optimization is the least cost scenario among all where cost of generation decreases to 11.15 billion US dollars in 2040.

8. Conclusion And Policy Implication

In this paper, a study has been conducted to estimate electricity demand and supply projections of Pakistan from 2018-2040 through energy modelling software LEAP. The alternate policy scenarios are developed in accordance with baseline scenario (existing policies). For modelling of the system, historical data of electricity sector of Pakistan was incorporated from 2004 to 2017 and electricity demand has been projected from the first scenario year 2018 to target year 2040 by three different models developed in LEAP. The three models include empirical model based on electricity growth rates of NTDC multiple regression studies of 2011, econometric model based on economic indicators taken from NTDC regression analysis report and econometric model with linear regression based on predictions of economic variables by linear regression approach. Electricity demand projected from the three models are found to be 470 TWh, 530 TWh and 230 TWh for 2040 which was 57.35 TWh in the base year 2004 and 94.47 TWh in 2017. Electricity generation was projected for meeting the demand under baseline scenario which was based on government policies. The electricity generation projected for 2040 for Pakistan with econometric model with linear regression estimated to be 270 TWh which was 80.5 TWh in 2004 and 119.35 TWh in 2017.

From the economic analysis, delay in hydro scenario was found to be the most expensive scenario with a total loss of 88 billion US dollars up to 2040. Green energy scenario and energy conservation scenario saves around 13 billion US dollar and 91 billion US dollar respectively. Optimization scenario saves a huge cost of 461.7 billion US dollar compared to baseline scenario because of less running cost and negligible fuel import cost. The most suitable pathway for meeting the demand-supply gap of Pakistan is the energy conservation policy scenario in which generation plan target could be well achieved by targeting 20% energy conservation strategy by using energy efficient devices. This saves around 91 billion US dollars from 2018 to 2040 by reducing demand to 192TWh and generation to 226TWh. The reduction in demand in energy conservation policy would lead to less power infrastructure investments as the need of new power plants and capacity expansions are reduced. Government should make an energy security plan to recognize the energy conservation policy to cater demand and supply deficit with sustained economic growth. The electricity generation mix presented in above section can be followed to achieve the desired results. The proposed methodology in this paper can help energy planners in forming a new policy.

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Not applicable.

Consent for publication
Not applicable

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Appendix

Table A-1. Sectoral GDP of Pakistan [1, 50]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| GDP (%) | 7.5  | 9.0  | 5.8  | 5.5  | 5.0  | 0.4  | 2.6  | 3.6  | 3.8  | 3.7  | 4.1  | 4.1  | 4.6  | 5.4  |
| Agriculture | 2.4  | 6.5  | 6.3  | 3.4  | 1.8  | 3.5  | 0.2  | 2.0  | 3.6  | 2.7  | 2.5  | 2.1  | 0.2  | 2.1  |
| Industry | 14.0 | 15.5 | 8.7  | 9.0  | 6.1  | -4.2 | 1.4  | 2.5  | 2.1  | 4.9  | 5.7  | 3.9  | 3.7  | 5.8  |
| Commercial | 5.9  | 8.5  | 6.5  | 5.6  | 4.9  | 1.3  | 3.2  | 3.9  | 4.4  | 5.1  | 4.5  | 4.4  | 5.7  | 6.5  |

Table A-2. Historical population of Pakistan [50]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Population (Million) | 149.7 | 152.5 | 155.4 | 163.1 | 166.8 | 169.1 | 172.3 | 177.1 | 180.3 | 183.6 | 189.4 | 195.3 | 201.4 | 207.8 |

Table A-3. Electric consumers in different sectors of Pakistan [68]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Domestic (Million) | 13.1 | 13.9 | 14.8 | 15.8 | 16.7 | 17.4 | 18.3 | 19.6 | 19.6 | 20.4 | 20.8 | 21.1 | 21.6 | 22.0 |
| Agriculture (Thousand) | 200 | 200 | 220 | 230 | 240 | 260 | 270 | 280 | 288 | 300 | 280 | 297 | 310 | 320 |
| Industry (Thousand) | 230 | 233 | 244 | 255 | 263 | 270 | 280 | 290 | 300 | 317 | 290 | 299 | 307 | 316 |
| Commercial (Thousand) | 2300 | 2370 | 2470 | 2570 | 2660 | 2700 | 2800 | 2870 | 2900 | 3000 | 2890 | 2900 | 3000 | 3180 |
| Others (Thousand) | 10.8 | 10.8 | 11.3 | 12.3 | 12.8 | 13.1 | 14.3 | 14.0 | 13.9 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 |

Table A-4. Demand sectors electricity consumption of Pakistan in Thousand GWh [4, 17, 38, 39, 69]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Domestic | 25.8 | 27.6 | 30.8 | 32.9 | 32.8 | 31.7 | 33.6 | 35.2 | 34.8 | 35.4 | 38.8 | 40.3 | 43.5 | 48.0 |
| Agriculture | 6.7 | 7.0 | 8.0 | 8.2 | 8.5 | 9.7 | 9.0 | 8.5 | 7.7 | 8.2 | 8.0 | 8.5 | 9.2 |
| Industry | 17.4 | 18.6 | 19.8 | 21.2 | 20.8 | 19.3 | 19.8 | 21.1 | 21.7 | 22.1 | 24.1 | 24.9 | 25.0 | 24.0 |
| Commercial | 3.7 | 4.0 | 4.7 | 5.3 | 5.5 | 5.2 | 5.6 | 5.7 | 5.9 | 6.3 | 6.4 | 7.1 | 7.8 |
| Others | 3.9 | 4.1 | 4.4 | 4.7 | 4.7 | 4.7 | 4.9 | 5.2 | 5.0 | 4.8 | 5.0 | 4.8 | 5.2 | 5.5 |
Table A-5. Fuel wise electricity generation of Pakistan in thousand GWh [4, 17, 38]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Coal  | 0.2  | 0.2  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.0  | 0.1  | 0.1  | 0.1  | 1.1  |
| Oil   | 12.3 | 13.0 | 18.6 | 26.4 | 29.9 | 25.5 | 35.6 | 35.8 | 35.3 | 35.8 | 37.2 | 38.4 | 36.0 | 38.8 |
| Natural gas | 39.0 | 43.2 | 40.9 | 37.0 | 35.6 | 39.1 | 32.6 | 29.1 | 30.2 | 28.2 | 30.8 | 31.2 | 37.6 | 38.3 |
| Hydro | 27.5 | 25.7 | 30.9 | 31.9 | 28.7 | 28.2 | 28.5 | 32.2 | 28.6 | 30.0 | 32.2 | 32.6 | 34.6 | 32.1 |
| Nuclear | 1.6  | 2.5  | 2.3  | 2.1  | 2.8  | 1.5  | 2.7  | 3.0  | 4.9  | 4.2  | 4.7  | 5.3  | 4.2  | 6.3  |
| Wind  | -    | -    | -    | -    | -    | -    | -    | -    | 0.01 | 0.032 | 0.26 | 0.5  | 0.7  | 1.4  |
| Solar | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 0.03 | 0.2  | 0.6  |
| Bagasse | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 0.31 | 0.5  | 0.9  |

Table A-6. Capacity of power plants of Pakistan in thousand MW [4, 39, 69]

| Years | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Coal  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  | 0.7  | 0.8  |
| Oil   | 4.2  | 4.2  | 4.2  | 4.9  | 4.9  | 4.9  | 5.2  | 5.4  | 5.6  | 5.9  | 6.1  | 6.3  | 6.6  | 6.8  |
| Natural gas | 7.4  | 7.4  | 7.3  | 6.5  | 6.0  | 7.1  | 7.5  | 7.6  | 7.8  | 8.0  | 8.2  | 8.4  | 8.7  | 8.9  |
| Hydro | 6.5  | 6.5  | 6.5  | 6.5  | 6.6  | 6.6  | 6.6  | 6.7  | 6.9  | 7.1  | 7.1  | 7.1  | 7.1  | 7.1  |
| Nuclear | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.8  | 0.8  | 0.8  | 0.8  | 0.8  | 0.8  | 1.1  |
| Wind  | -    | -    | -    | -    | -    | -    | -    | -    | 0.001 | 0.05 | 0.1  | 0.3  | 0.3  | 0.8  |
| Solar | -    | -    | -    | -    | -    | -    | -    | -    | -    | 0.1  | 0.4  | 0.4  |
| Bagasse | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | 0.1  | 0.1  | 0.3  |

Table A-7. Cost characteristics of energy technologies of Pakistan [40, 41, 70-73]

| Process | Coal | Oil | Gas | Hydro | Nuclear | Wind | Solar | Bagasse |
|---------|------|-----|-----|-------|--------|------|-------|--------|
| Capital cost ($/kW) | 2548.8 | 1200 | 1200 | 2600 | 4000 | 1480 | 1067 | 1000 |
| Fixed O & M cost ($/kW) | 35.6 | 48.5 | 14.7 | 29.04 | 87.6 | 60.24 | 26.5 | 40.6 |
| Variable cost ($/MWh) | 1.5 | 12.99 | 2.07 | 2.04 | 8 | 0.4 | 2.4 | 1.37 |
| Fuel cost ($/MWh) | 36.36 | 149 | 43 | - | 8.16 | - | - | 40 |
| 2030 | 36.36 | 202 | 72 | - | 8.16 | - | - | 40 |
| Process efficiency (%) | 35 | 51 | 46 | 100 | 33 | 100 | 100 | 35 |
| Maximum availability (%) | 90 | 80 | 70 | 90 | 85 | 70 | 25 | 56 |
| Lifetime (years) | 30 | 30 | 30 | 40 | 30 | 20 | 25 | 25 |