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Co_2 Reduction Potential, Economic Analysis and Sustainable Policy of the Power Generation Sector of Pakistan

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Abstract

This paper suggests that Pakistan has a significant energy supply and demand mismatch. In the energy sector, accurate measurement is necessary to provide a prediction that aids in creating a strong framework for future work and policy. We must quickly shift energy generation toward renewable energy sources in order to keep global warming under strict control and recognize it as a serious issue. Pakistan should move as quickly pace to shift its energy production from fossil fuels to clean and renewable energy that needs US $ 211 million for an increase in the supply of electricity per capita. This study is done for the analysis of the decarburization potential of Pakistan's energy sector to increase the clean energy input in line and reduce CO_2 emissions. Two different scenarios are considered in this analysis based on the results a conclusion has been drawn in cross-examination of the scenarios best suitable for mass application at the national scale. To make Pakistan a greenhouse gas-free nation at a global scale decarburization of energy is inevitable. While analyzing carefully it is suggested that Pakistan has the correct and up-to-the-scale potential of decarburization of energy at 23% per annum gradually till 2035 with 12 million US dollars cost involved overall.

Keywords: Decarburization, CO_2 emissions, Clean and Renewable energy, LEAP Energy Analysis

1. Introduction

It is now a fact that more the fossil fuels are burnt, more is the production of Greenhouse Gases (GHG) in the environment and warmer the globe will be [1]. Due to the increase in global temperature, a very adverse effect has been seen in the recent past that severely hit the global climate [2]. The current global condition demands decreasing the burning percentage of fossil fuels and focusing on renewable energy sources to cater to the declining climate conditions. Pakistan is sanctified with renewable energy resources with a potential of 346000 MW for wind, 2900000 MW for solar, 3000 MW for biomass, 868 MW for small-scale, and 41270 MW for large-scale hydroelectric power projects.[3] Additionally, in the future, the main diminishment in GHG emanations will be compulsory in arrange to restrain the worldwide mean temperature increment to 20 °C [4]. Besides its Vision 2025, Pakistan has main diminishment in GHG emanations will be compulsory in arrange to restrain the worldwide mean temperature increment to 20 °C [4]. Besides its Vision 2025, Pakistan has

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given its assurance ahead of sustainable development with a pledge to the matter of altering of worldwide climate within the nationwide level energy strategies [5]. This research provides a sustained solution from electricity problems and helps for long-term projection in the demand and supply of electricity keeping in view the GHG emission reduction from the energy sector [6]. The reported electricity supply growth rate from 2006-16 was 2.1% only. Pakistan needs more capital to create supply resources, and poor infrastructure and delayed policy implementation is the basic reason of the slow growth in the supply side [7]. In 2016 the electricity demand-supply gap was 31.6 TWh annually which led to 2.5% decrease in GDP and more than 0.5 million unemployment in the industrialized sector [8].

In Pakistan demand of energy sector met by different resources the energy consumption of Pakistan was reported as 110.5 GWh in 2015 [9] which upstretched to 118.6 TWh with growth rate is 7.3% in 2016[10]. For the year 2017 the generation was 123 TWh with a growth rate of 4.8%[11]. Special Parliamentary Committee on Energy Crisis reports that liability worth $8.07 billion in 2016 is being charged because of mismanagement of subventions in power sectors and electricity short fall of 7000 M[12]. During 2018 and 2019, more than 10% of the energy was produced using pricey imported oil, and more than 12% of the generation mix is dominated by thermal power. was founded on coal technology with increased CO_2 emissions[13]. For reliable electric supply that will affect future polices and implications. United Nations Framework Convention on Climate Change (UNFCC) concluded an agreement at COP21 and take measures to control these emissions[14]. Similar work has been published (26) has short comings that will be covered in current research. These additions include:

1. Pakistan's Intended Nationally Determined Contributions (INDC) commitments towards emission control in country fuel mix [15].
2. *China Pakistan Economic Corridor* (CPEC) Early harvesting projects addition which includes Coal power plants, Natural Gas and Fossil fuels and energy mix has been changed in Business as Usual (BAU) scenario [16].
3. CPEC long term projects scenario will be considered as it will have impact on energy mix and CO2 emission [17].

The impact of these changes have been discussed as the country energy mix in 2016 to 2035 and it will be different than the previous work [18]. This study's main objective was to investigate the asymmetric effects of CO_2 emissions from various sources on Pakistan's economic development. The results of this analysis, which used yearly data from 2016 to 2035, showed that CO_2 emissions have a negative influence on the nation's long-term growth. Therefore, the goals of this study to provide a comprehensive, system-wide assessment and analysis of the dynamics of Pakistan's power systems, an electricity supply mix that will allow Pakistan to affordably reach its CO_2 emission reduction target. We used three different scenarios to examine the system-wide endogenous interactions among generation technologies, fuel resources, demand, capital investments, CO_2 emissions, production costs, and electricity prices. The overall assessment of recent studies and earlier studies in the context of Pakistan shows that, despite the efforts of many authors to investigate the variables influencing carbon emissions in the nation.

1.1. Energy Demand and Supply Analysis

With each passing day, new appliances that consumes energy are being installed and utilize [19]. Due to increase in consumption, the demand and supply gap has widen [20]. In year 2018-2019 energy availability per capital declined 0.64% and in 2016 it declined

to 3.09% [21]. The detailed analysis on demand and supply has been discussed in following sections.

1.1.1. Energy Demand Analysis

In the recent scenario the energy supply and consumption gap are growing by time to time as the current generation of National Transmission & Dispatch Company (NTDC) and K-Electric is 22148 MW in 2019 the demand in peak hours for both 28470 MW and the shortfall is 6328 MW which is considered to be a giant difference. A growth in energy sector has been noted at 7.5% in the year 2020 and stands at 37,972MW as compare to 33,452MW. Pakistan has about 60GW potential to generate electricity from Hydel resources but so far only 10GW has been tapped. Wind energy potential is about 50GW and only 1GW capacity has been installed and wind energy projects are gradually moving forward, and solar potential is more than 100,000GW in a state of neglect. The current installed capacity for Solar PV is about 800 MW [22]. Pakistan main sector which uses energy comprises of domestic, industry, transportation, electricity generation, agricultural, commercial and other public services [5]. To estimate the Energy demand forecast it is assumed that the same trend will be followed up to the final year [22]. Table 1 shows forecasts to meet demand of electricity generation for the country. From 2014-2015 to 2018-2019 installed capacity has been increased [9]. Operating capacity to be increased almost 20,849 MW to 37,272 MW by the end of 2019 [15]. Table 1 shows the accumulation capacity for electricity generation by fuel being used [14] [23]. On other hand Table 2 gives imbedded view that hydro, nuclear and renewables investments are going to priority for next 10 years [16][24].

Table 1. Proposed demand.

	Unit	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21
KE (SC)	MW	3,397	3,582	3,809	4,092	4,509	4,834	5,327
NTDC System	MW	20,836	21,924	23,213	24,762	26,530	36,166	39,457
Total Demand	MW	24,233	25,505	27,022	28,855	31,039	38,461	42,812

Source: "*Power Market Survey, NTDC"*

Table 2. Generation capacity (MW) by 2020-21.

	Hydel	Nuclear	Oil	Solar/Wind	Coal	Gas	Total	Cumulative
Existing	6,928	650	3,896	50	150	9,175	20,849	20,849
				Addition				
2016	-	-	425	250	-	-	675	21,524
2017	-	340	-	680	-	-	1,020	22,544
2018	2,526	340	-	1,720	-	2,400	6,986	29,530
2019	1,522	-	-	-	4,920	1,300	7,742	37,272
2020	9,714	2,490	-	1,690	-	-	13,794	51,066
2021	9,874	2,490	-	1,999	-	-	14,363	65,429
Total	30,564	6,310	4,321	6389	5,070	12,875	65,419	

1.1.2. Energy Supply Analysis

Pakistan's energy blend is extremely reliant on power generated by fossil fuels powered plants instead of clean energy[18]. Present scenario represents that electricity produces from gas 25.8%, oil 37.9%, hydel 28.8%, nuclear 3.7% and a small fraction of electricity is imported [12]. Dependence of imported oil is about 85% of total supply which makes the energy mix so critical and adversely effects the economy. Table 3 shows the reserves for production [6].

2. Methodology

LEAP (Long range energy alternative planning system) is used as simulator for this investigation[19]. LEAP is most broadly used simulation tool for energy policy analysis and climate change vindication assessment [8]. Three approaches are used for demand modelling in LEAP [15]. End use approach or bottom-up approach is data intensive approach [19]. To opt this approach, there should have detailed data sets of sectors/ sub sectors/ end use and devices [10]. Top down or Econometric approach which is also used in this analysis is less data intensive approach but demands more detailed historical time series data [2]. In this approach data sets are divided into sectors and fuels only [1]. Third one is decoupled approach which is basically combination of the above two approaches and therefore intermediate data sets are required for this approach.

Table 3. Reserves to production (R/P).

	Oil	**Coal**	**Natural Gas**
Production (MTOE)	4.2	1.5	430.9
Reserves (MTOE)	49.7	7,775	411
R/P Ratio (Years) 11.8	13.2	-	5050
World Average			
R/P Ratio (Years)	40	110	59

Performance individualities of power generation machineries and cost is very hard to treasure for Pakistan on costs, as per literature review and academia level investigate [9]. Cost related data depends on technical parameters and local condition's [2]. Department of Energy used the data source for value and performance associated data because to unavailability of actual data of generation for power. Literature reviews of previous researches and approved papers was studied to accumulate obligatory data of power generation for Pakistan [8]. The Cost statics of the electricity generation is being adapted from the past study of power plants as shown in Table 4.

Table 4. Cost of power generation technologies.

Parameters	Nuclear	Gas	Furnace oil	Hydel	Renewables	Coal
Capacity Factor %	75	65	45	53	23	75
Process efficiency	33	46	51	60	44	42
Lifetime in Years	30	30	30	40	28	30
Capital Cost ($/MW)	5945	1104	910	5940	2671	3636
Fixed O & M Cost ($/KW) - Year	100.28	10.1	14.19	31	23.4	42.1
Variable O&M Cost ($/MWh)	2.3	2	3.76	4.45	0	4.6

2.1. Scenario development

Business as Usual (BAU) scenario is built on the Pakistan's government planned the development of electricity capacity, energy facilities, and proposed mitigation options[9]. BAU scenario is aligned with Vision 2025, CPEC projects and Pak-INDC [14]. This research used the BAU scenario as a standard for the development of two alternate scenarios, which are 450 and Green Pakistan (GP) [17]. The GP and 450 scenarios have had their own policy strategies. LEAP software has many limitations regarding the investigation of power plants with transmission and circulation losses to deal with this problem, the total losses have been considered [12]. In this model, it is assumed that the electricity generated by power plants can be transmitted at any time to variable load deprived of any limitation [19]. As Pakistan has limited data about power plants (life span), so data was taken from public sector power plants about their retirement [15]. The LEAP model considers yearly generation profile and does not calculate hourly profile [9]. There are two branches the demand branch and the supply branch in leap model 6. The demand branch is fabricated of electricity generation from different sources containing coal, hydel, oil, gas and renewables [15]. On the other hand, supply branch is divided into transmission and distribution for electricity[10].

3. Results and discussion

This scenario is developed using Leap model provides energy mix for generation of electricity in Pakistan for period 2016-2035 as per present administration strategies, i.e. standardization of base year in the model [19]. BAU scenario shelters the existing fuel mix and related skills which has been adjusted for first year of the exhibiting period which is shown in Figure 1 [15]. This scenario pleases the initial state of summit electricity request and assists as a locus scenario for emerging two alternate scenarios 450 and GP scenarios based on the same modelling context [9]. Subsequent sections deliver comprehensive details for the fixed and generation capacity by means of different energies and knowledges with CO_2 releases and total capital cost estimates [25].

Each scenario's generation and installed capacity is given in Table 5 Shows the results of three scenarios in 2016 electricity generated by BAU is 111,492 GWh which gradually increased to 335,546 GWh till 2035 with installed capacity of 67004 MW [7]. The value of capacity and output in BAU from 2016 to 2035 is constant because no more projects are under process in these years [12]. BAU scenario meets the future energy requirement of Pakistan[19].

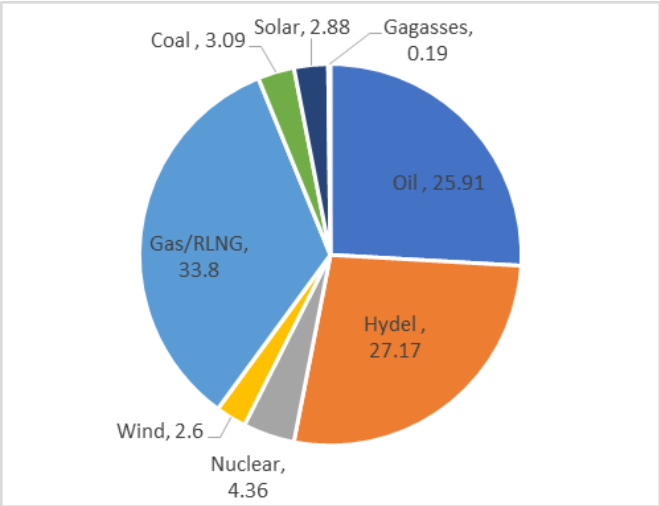

Figure 1: Energy mix 2017.

3.1. Business as Usual (BAU) scenario

In business-as-usual scenarios considered all the government short term plans of installed capacity and calculate the overall generation till 2035 [17]. Shows the results of three scenarios in 2016 electricity generated by BAU are 111,492 GWh which gradually increased to 335,546 GWh till 2035 with installed capacity of 67004 MW [19]. The value of capacity and output in BAU from 2028 to 2035 is constant because no more projects are under process in these years [15][26]. BAU scenario meets the future energy requirement of Pakistan [20-21]. As shown in Figure 2, the installed capacity and Figure 3 the generation capacity of this BAU scenario.

Table 5. Three scenarios electricity generation and installed.

Years	BAU Capacity MW	BAU Output GWH	450 Capacity MW	450 Output GWH	GP Capacity MW	GP Output GWH
2016	25374	114491	25373	114492	9173	41947
2018	37302	177144	31868	142476	14296	64058
2020	45674	224144	36449	161099	17634	78309
2022	50401	248566	43074	189212	21852	99704
2024	54780	271370	49350	215706	25721	99704
2016	58855	292762	55321	240789	29282	137849
2028	62929	314154	61293	265871	32850	171567
2030	67004	335546	67265	290952	36415	174589
2035	67004	335546	67265	290952	36415	174589

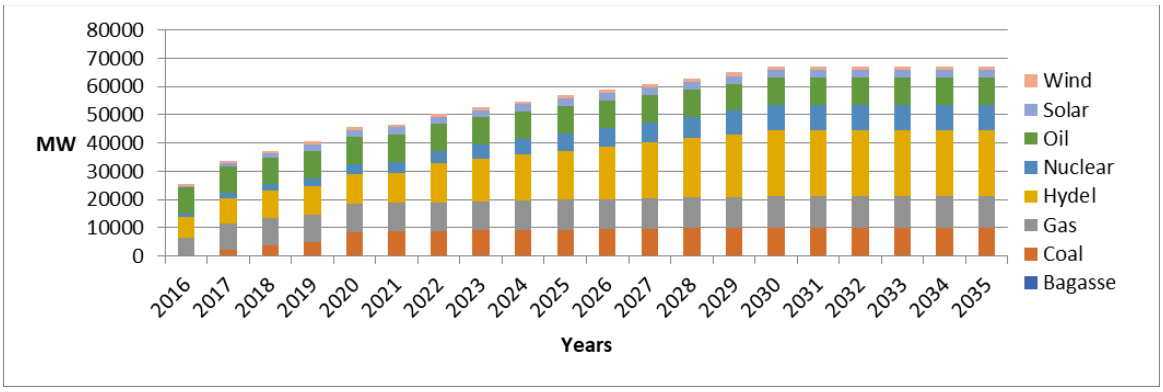

Figure 2: Generation capacity in BAU.

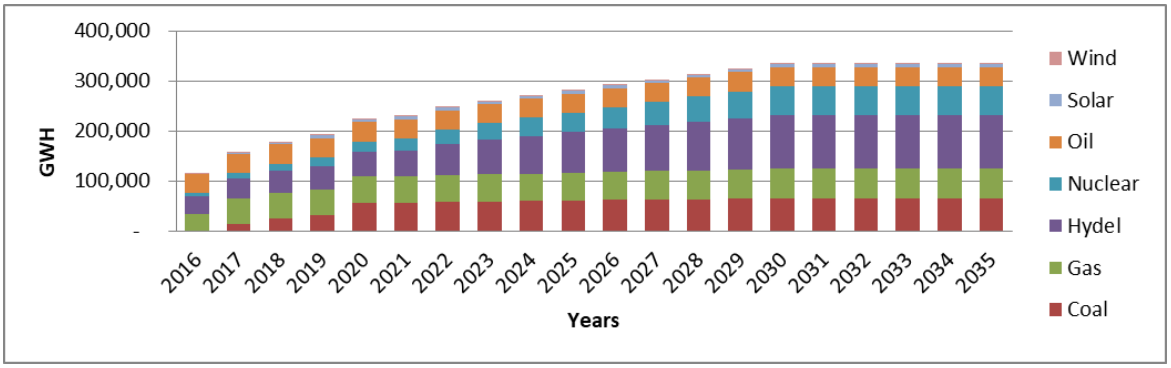

Figure 3: Installed capacity of BAU.

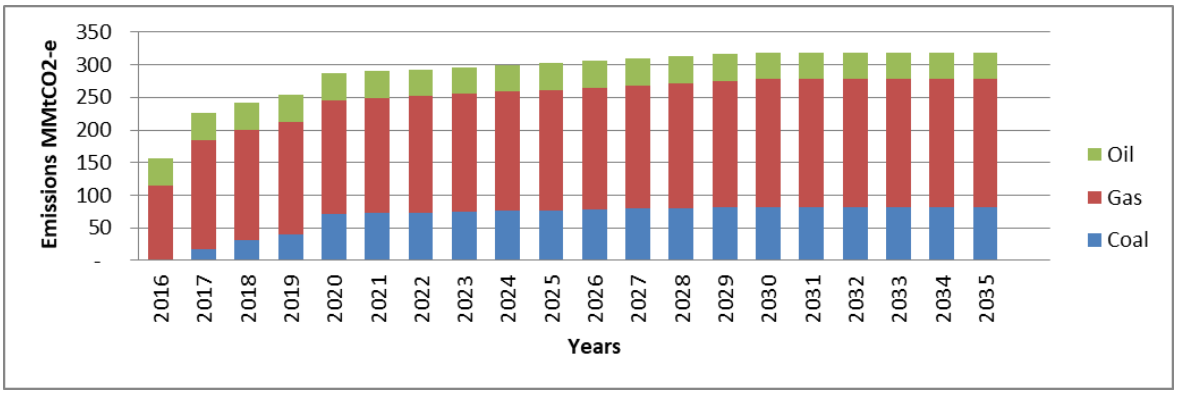

Figure 4: Global warming potential of one-hundred year in BAU scenario.

In BAU scenario electricity generation form solar is 230GWh in 2016 and it is just increased to 5560 GWh, similarly wind generation increased from 1282 to 2156 GWh in same duration [16–18]. But in the case of coal the value is increased exponentially from 210 to 64168GWh [8]. Due to higher rate of gas and coal generation electricity, BAU has highest emissions [10]. One hundred-year GWP owing to generation of electricity by consecutively progressions is regularly increasing from 150 $MMtCO_2$ equivalent in 2016 to 300 $MMtCO_2$ equivalent in 2035 in BAU scenario. As shown in Figure 4. BAU scenario did not discuss the concept of CO_2 emissions which is very important for Pakistan future

road map. Paper based concept based on vision 2025 which is not implemented by Government Pakistan [2]. Mover fuel mix is entirely different as Pakistan major projects are based on Coal and LNG which is major part of CPEC. Current research includes all major projects which is signed by GOP, emissions by these projects and their impact of Pakistan environment [17]. The calculations also do not include new energy or waste energy, which are not recognized as renewables by international standards. The supply side of the BAU scenario shows a progression in which nuclear energy eventually replaces conventional sources, such as coal-fired power plants. This is as a result of current government initiatives to close the outdated coal-fired power facilities and control new construction [27].

3.2. 450 Scenarios

This scenario is very important in this research as it fulfill the commitments of Intended Nationally Determined Contributions (Pak-INDCs) to cap the CO_2 emissions [8]. This scenario is based on International Energy Agency (IEA) 2016 policy according to which minimum share of non hydel renewable must be 25% of total energy mix 13. But in Aized et al [2] work share of renewable is not enough to meet the requirements of UNFCCC [10]. In 450 scenarios, renewable energy all includes which was not the part of government policy but necessary to reduce the CO_2 emission to meet the Paris agreement and fulfil the energy demand of country [17]. In 450 scenario 25 to 34% CO_2 is cap up which has a great impact of generation from fossil fuels and this is done by introducing low carbon mitigation technologies and increase of nuclear energy [15]

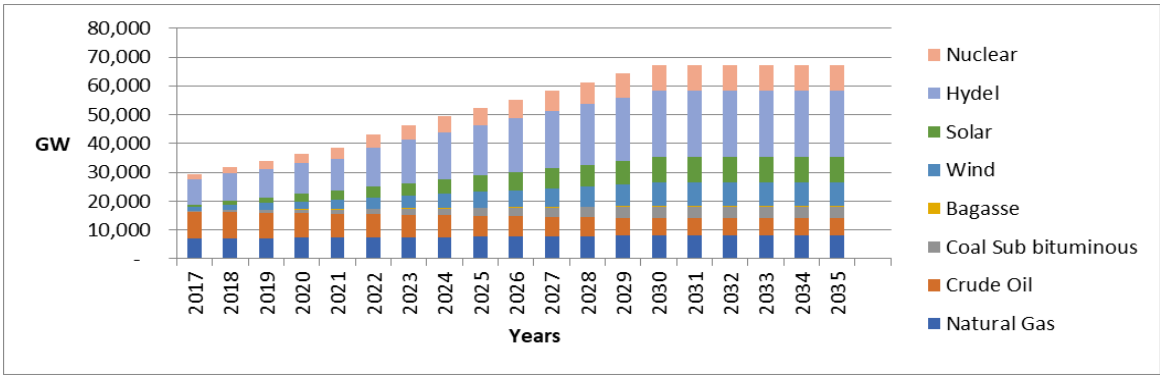

Figure 5: Installed capacity of 450 scenario.

Comparison with BAU scenario, Figure 5 represents that the share of generation from Coal is reduced from 64188 to 26411 GWh in 450scenario [10]. Likewise, part of wind and solar is improved from 2156 and 5560 GWh in BAU scenario to 13930 and17730 GWh respectively in the 450 scenarios [14]. This scenario shows a major change in installed capacity of solar, wind, hydro on relating with the BAU [16]. As 450 scenarios are intended to reduce 25 to 34 % of CO_2 emissions progressively by the year 2035, the results show 34% emissions is reduced by giving partiality to minor carbon electricity generation machineries, as demonstrated in Figure 6 [19]. The main part of CO_2 emission from the coal and natural gas-based electricity generation during the period (2016-2035). This scenario gives penchant to CH_4 than coal to meet the 25 to 34% emission reduction.

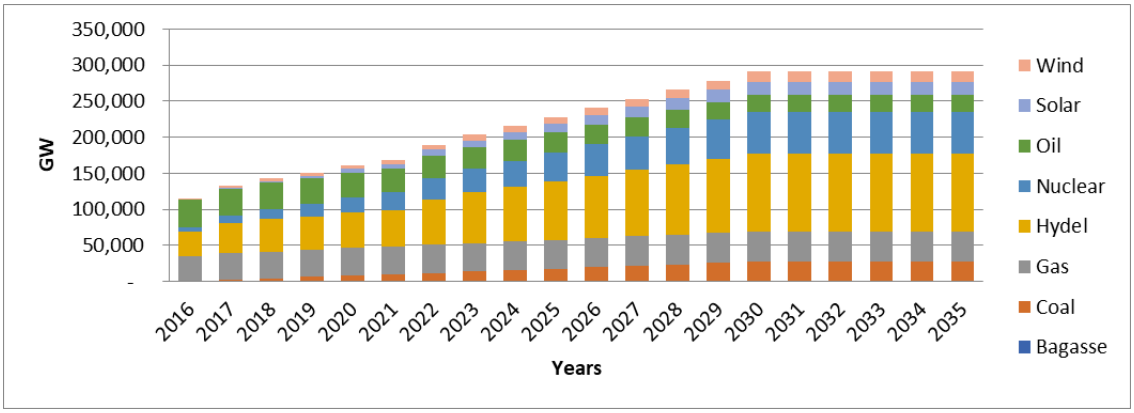

Figure 6: Electricity generated in 450 scenarios.

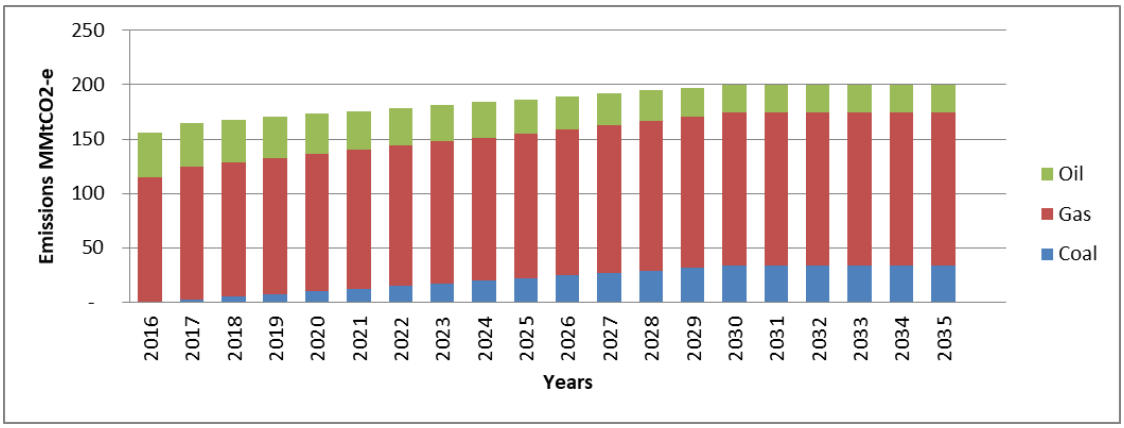

Figure 7: CO2 emissions.

One hundred-year GWP due to generation of electricity by successively procedures is regularly growing from 150 $MMtCO_2$ equivalent in 2016 to 200 $MMtCO_2$ equivalent in 2035 in BAU scenario [12]. Reduction of 34% can be achieved as compared to BAU scenario which is shown in Figure 7 [16]. The Leap model guesses that the electricity generation area in Pakistan, under 450 scenarios, will need a projected amount of 223.1 million US$ as shown in Figure 8.

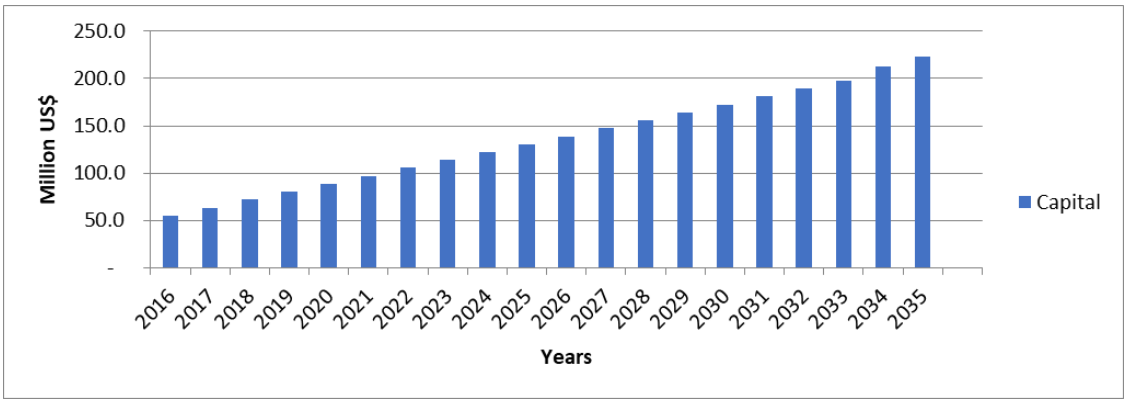

Figure 8: Capital cost for 450 scenarios.

3.3. Green Pakistan (GP) Scenario

The scenario is totally based on renewable energy that guesses the progress of mounted generation capacity from a 9136MW [19] in year 2016 to 36415 MW in year 2035 under GP scenario, with main involvement from Solar, hydro and wind as shown in Figure 9. The electricity generation through green Pakistan scenario is totally on renewable resources and emission free but unable to meet the demand of energy [15]. Figure 10 gives a clear image of generation in green Pakistan scenario.

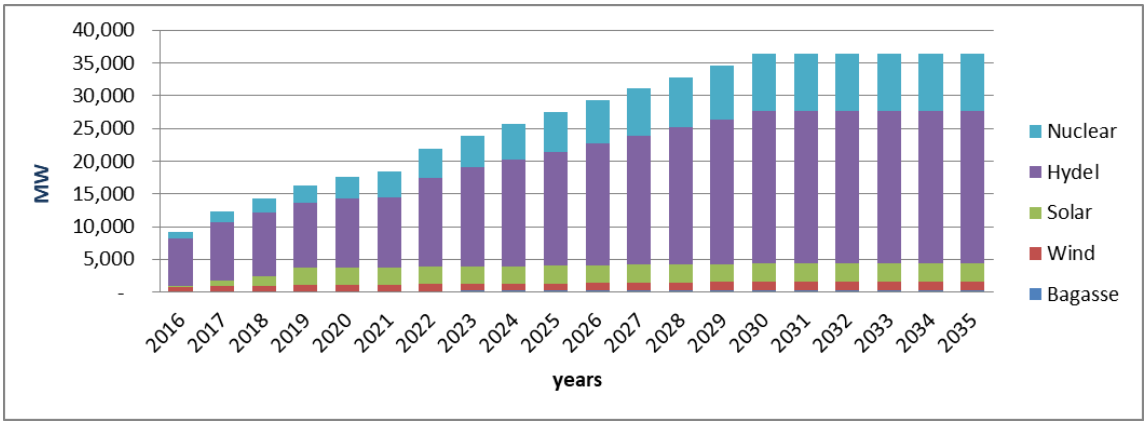

Figure 9: Electricity Installed Capacity in GP scenario.

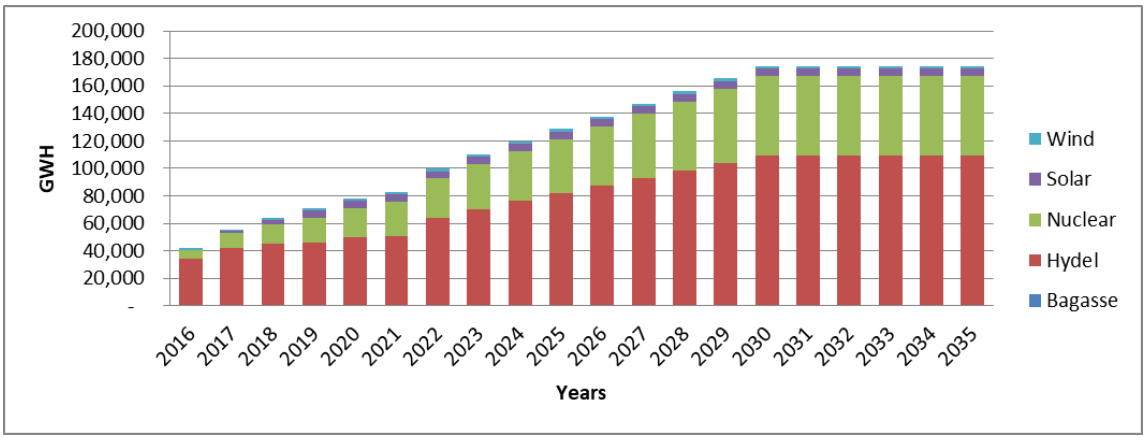

Figure 10: Electricity generated GP scenario.

4. Conclusions

The Pakistan LEAP model was established undercurrent study period 2016-2035 to encounter the electricity claim in the country. Firstly, the BAU scenario was rectified for year 2016 and alternate scenarios namely, 450 and green Pakistan scenarios to lessen the CO_2 emission steadily in the end year, Green Pakistan is totally emission free. Business as Usual scenario shows a variety of energy-mix but is the emissions rates as high ranges from 155.8 $MMtCO_2$ equivalents in 2016 to 319.2 $MMtCO_2$ equivalents in 2035 with a generation of 335,546 GWh by the year 2035. Its capital cost ranged from 55 to 211.5 million US$ during the study period.

450 scenarios are based on IEA guidelines in which share of electricity generation from non hydel renewables is 25%. The 450 scenario ensures 25 to 34 % cap on the CO_2 emissions steadily by the year 2035. The main part of CO_2 emission during the study

period 2016-2035 is from the fossil fuel-based electricity generation. Cost of this scenario is 5.6% higher than BAU but through this modeling we can achieve Pak-INDC (Pakistan's Intended Nationally Determined Contribution) goal to limit the global mean temperature to 20 °C. Electricity generation cost ranges from 34.6 million US$ in 2016 to 151.7 million US$ in 2035. But it does not meet the electrical demand, but it can be implemented in conjunction with other scenarios.

Potential of Global warming for 100 years due to energy consumption is rapidly growing from 155.9 $MMtCO_2$ equivalents in 2016 to 319.2 $MMtCO_2$ equivalents in 2030 whereas. This growing potential of CO_2 emissions is an impending threat for health. Consequently, it is ominous requirement of period to rise our dependence on renewables not for electricity generation also for transport sector. Scenario investigation with price and atmosphere evidently directs that electricity generation by renewables is the superlative choice for our country. In our homeland maximum availability of wind, solar and hydel is one of the best in the world. Therefore, the propaganda about the availability of renewables must be closed. However capital costs are high as compared to thermal. But in long term prospective when we analyze costs with environmental effects and fuels renewable generation has much lower costs than other technologies.

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