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Long Term Optimal Energy Planning and Policy Formulation for Pakistan

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ABSTRACT

Authors used Long-range Energy Alternatives Planning (LEAP) model in this paper to develop and analyze future energy demand, production and CO_2 emissions in Pakistan from 2020 to 2040. The model is developed based on Governmental Progressive Scenario (GPS), which forecasts sector wise (agriculture, commercial, domestic, industrial and others) energy demand of the country, and analyzes future energy supply pattern based on the domestic energy sources like RLNG, hydro, coal, natural gas, nuclear, furnace oil and renewable (wind, solar, biomass). The results of this study show that the growth rates of future energy supply and demand are 18% and 11% respectively. CO_2 emissions based on future energy production are also forecasted from 2020 to 2040 which is showing declining trend due to the use of cleaner technologies in the future. The total cost of energy projects is also forecasted based on net present value at a discount rate of 4%, 8% and 12%. It is found that energy projects cost will be 50% less at discount rate of 8%. The results of this study are useful in making long term energy and environmental planning and policy formulation in Pakistan.

1. INTRODUCTION

One of the most significant drivers of any country's economic growth and development is electricity. Large businesses and small commercial services, as well as industrial operations, transportation, medical and education systems, household appliances, are all based massively on electricity [1]. With population expansion and changing lifestyles around the world, global power consumption is continuously increasing [2]. Electricity generation is a significant concern, particularly in underdeveloped countries. Fossil fuels are the dominant energy assets on a global scale and provide about 80% of the world's electricity [3]. CO_2 emissions are produced in greater quantity when electricity is generated from fossil fuels. These CO_2 emissions have detrimental environmental consequences, such as climate change, global warming, and health issues for all living organisms [4], [5].

Power generation in Pakistan is primarily based on imported Iranian furnace oil and natural gas [6]. Pakistan has some substantial coal reserves in Thar but this capacity is not fully utilized for power generation. However few fossil fuels-based power generation projects are nearby to completion phase [7]. Pakistan is currently on a route towards destructive climate change energy mix [8]. Pakistan's CO_2 emissions are 250 million tons by 2020 which are expected to reach 2340 million tons by 2030, if fossil fuel slackens are maintained [9]. The energy and transportation sectors account for over half of Pakistan's national CO_2 emissions, while agricultural sector accounts for the least [10], [11].

Per capita usage of Pakistan's electricity is 418 kWh, which is significantly lower than the global average [12]. In 2007, the electricity shortage was predicted to be 1 to 2 GW, but by 2019 it had grown to 7 GW [13]. During the summer, several enterprises have been forced to close or downturn operations, while residential users in both urban and rural areas have been subjected to daily power outages of roughly 12 hours [14]. Due to rising demand and supply unreliability, the electricity crisis may intensify in the future years unless serious efforts are implemented. To meet this difficulty, the Pakistani government (PG) established a new power plan with name Integrated Generation Capacity Expansion Planning (IGCEP) in 2018 and 2021 respectively [15], [16]. To develop a power production capacity that could meet country's electrical demand is the purpose of the power policy. To achieve this long-term aim, the government devised a strategy centered on

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moving country's electrical energy production mix toward low-cost primitive sources such as Regassified Liquefied Natural Gas (RLNG), hydro, coal, natural gas, nuclear, furnace oil and renewable (wind, solar, biomass) with coal accounting for the majority of the total [15], [16]. A comprehensive planning exercise is needed by incorporating the energy modeling tools to establish a future plan to support the PG efforts in overcoming the electricity shortfall is the main purpose of this research paper.

In this regard, energy modeling through a variety of computer-based tools are useful in devising energy plan [2]. Diverse energy planning models are available with various modeling methodologies to satisfy the energy planning requirements on a case-by-case basis globally. The well know models are ENPEP BALNCE (Energy and Power Evaluation Program), MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) MARKAL (MARKet Allocation), and LEAP (Long Range Energy Alternatives Planning).

Many nations around the globe such as Argentina, Greece, Nigeria, Taiwan, Panama, Greek, Tanzania and Indonesia have used these energy modeling techniques to formulate successful policies to solve crucial energy concerns, detail is given in Table 1 [4] alongside pros and cons of energy modeling tools are given in Table 2.

Table 1. Energy planning and policy development through energy modeling tools.

Country	Tool Name	Study purpose
Argentina	ENPEP BALANCE	Exploring various power supply options.
Greece		Forecasting long term CO_2 emissions.
Nigeria	MARKAL	Assessment of green energy assets and technologies.
Taiwan		Estimating low CO_2 emissions path.
Panama	LEAP	Forecasting future energy supply pattern.
Greek		Exploring future energy supply options.
Tanzania	MESSAGE	Identifying future energy production capacity.
Indonesia		Exploring power potential of nuclear and other sources.

Table 2. Pros and cons of energy modeling tools.

1	Tool	ENPEP BALANCE
	Pros	Uses step function for renewable generation.
	Cons	Complicated not user friendly.
2	Tool	MARKAL
	Pros	Provide results in terms of datagram's.
	Cons	Complex method for data analysis.
3	Tool	LEAP
	Pros	Develop multiple power plans and policies based on single input.
	Cons	Not considered economic factors.
4	Tool	MESSAGE
	Pros	Time horizon for analysis is user friendly.
	Cons	Troubleshooting is complex.

Among these energy modeling tools, LEAP is publicly available for research and development with simple features for the analysis of environmental sustainability and suggested energy supply pattern based on the domestic energy assets [17], [18]. LEAP is user friendly tool that easily track energy resource eradication, generation, and utilization across various energy sectors. The LEAP model required less socio and techno-economic data, as well as its built-in-technology (demand analysis and transformation model) and environmental database, are ideal for this investigation.

In Pakistan's example, there are just a few studies in the literature that have taken into account the present PG goals and policies. As a result, this study incorporates the most important considerations pertaining to Pakistan's electricity sector, as well as a future direction for Pakistan's sustainable energy system, by suggesting integrated energy plan efforts to devise energy policy, as well as keeping such efforts alive for future adjustments. Therefore, the Governmental Progressive Scenario (GPS) was established in LEAP to examine the future energy demand, production, and CO_2 emissions for the period 2020 to 2040.

Section 2 of the paper presents an overview of renewable and non-renewable sources in Pakistan and depicts future energy generation projects and retirement schedule of existing power generating units from 2020 to 2040. Section 3 presents the research methodology of the developed LEAP model. Energy transformation module and energy demand analysis module forecasted future energy demand, production, and CO_2 emissions under the GPS. Section 4 presents the results of future forecasted energy demand, energy production, CO_2 emissions and total cost of energy project. Decarbonization strategies and complementarities for the Pakistan's energy sector are presented in section 5. Finally, policy recommendation and conclusion is given in Section 6 and 7.

2. REVIEW ON NON-RENEWABLE AND RENEWABLE ENERGY SOURCES IN PAKISTAN FOR ENERGY PLANNING AND POLICY DEVELOPMENT

Renewable and non-renewable sources can help developing countries for achieving sustainable energy supply security. The discussion on the renewable sources and non-renewable sources with their potential for energy planning and policy development are briefly described below:

a. The assessment for Pakistan's solar energy potential is performed by Alternative Energy Development Board of Pakistan (AEDB) [19]. The results revealed that Pakistan is an ideal for solar power plant installation with greater range of solar radiation. Pakistan can produce 1600 GW of electrical power annually from solar source which is 40 times greater than present power generation [19].

b. Agriculture sector is the major driver of economy in Pakistan's. 62% population is living in the less developed or rural areas and 38% in the urban areas [20]. Agriculture residues produced from rural areas are greater in capacity which can be utilized for energy generation for meeting local energy demand. Pakistan can produce 100 GW of electrical power annually from biomass source which is more than twice as compared with the present power generation [20].

c. Pakistan's Meteorological Department (PMD) and AEDB conducted a survey on the assessment of wind energy with the National Renewable Energy Laboratory (NREL), USAID [21]. The results revealed that all the provinces of Pakistan are ideal for the installation of wind power plant. Pakistan can produce 346 GW of electrical power annually from wind source which is 5 times greater as compared with the present power generation [21].

d. Pakistan can generate 100 GW of power by utilizing geothermal source which is considered as an unexplored energy source till now in Pakistan. As per estimates, 5-10 cents per unit is the cost of energy production in Pakistan. Mostly, geothermal source is available in the seismic belt of Pakistan [22].

e. Maximum power (6.5 GW) is produced in Pakistan from hydro source as compared with the other sources. Country has potential to produce 100 GW power from hydro [23]. PG has planned to generate 16 GW of power from hydro source till 2025 [23].

f. 185 billion tons of coal capacity is available in Pakistan and country comes at rank 2 in the world after united state. Coal is available in all the provinces of Pakistan and requires attention to exploit for power generation. Presently, 12.8% is the share of coal in energy mix which is low as compared with the available reserve capacity [24].

g. The share of nuclear power is minimum in Pakistan's energy mix because of slower deployment of nuclear technology. Presently 2.5 GW of energy is produced from nuclear source in Pakistan which contributed 6.6% in total energy mix in 2021.PG decided to increase the nuclear generation by 2030 to 9 GW [25].

h. Natural gas is available in Pakistan with capacity of 282 trillion cubic feet (Tcf) [26]. Natural gas was the first source in Pakistan which was exploited for energy generation. Presently, natural gas peaked because of greater use in energy generation, industrial and domestic sectors. At the present consumption rate of natural gas, it is expected that it will exhaust after 17 years until and unless new natural gas fields will be discovered [26].

i. One third of energy is produced from oil resource in Pakistan. Pakistan occupies 22 million barrels of oil resource which is in huge quantity and almost enough to alleviate energy crises in Pakistan. But unfortunately, the domestic oil production is zero and economic sectors imported 83% oil from Middle East [27]. Ministry of Finance in Pakistan has estimated that country imported oil with over 11.35 billion US dollars in 2021 [28].

Table 3. Future energy projects.

Energy source-based capacity addition (MW)	Till 2025	Till 2030	Till 2035	Till 2040	Total
Solar	1,600	-	2800	1600	6000
Wind	1,500	-	3500	2000	7000
Nuclear	1,100	-	-	-	1100
Oil	-	-	-	-	-
Coal	-	-	7,260	16500	23760
Hydro	3,536	11,611	6,350	3550	25047
Natural Gas	-	-	-	400	400
Total	7,736	11,611	19,910	24,050	63,307

To overcome the energy crises in Pakistan, PG has planned to develop many energy projects consists on RLNG, hydro, coal, natural gas, nuclear, furnace oil and renewable (wind, solar, biomass) sources under the Integrated Generation Capacity Expansion Planning (IGCEP) in 2018 and 2021, respectively [15], [16]. As a result, nearly 63,307 MW of power capacity will be added in Pakistan's power system for the alleviation of energy crises in the country [29], [30]. In this perspective, future power projects are assessed, and retirement schedule of existing power generation units are undertaken for this study as given in Table 3 and Table 4 [15], [16].

Table 4. Retirement schedule of existing power generation units.

S. No	Plant Name	Units (MW)	Retirement Year
1	Jamshoro	1x200 and 3x170	2023
2	Kotri	1x107	2025
3	Guddu	2x60 and 2x140	2023
4	Guddu	2x280 and 1x360	2023
5	Muzaffargarh	5x177 and 1x245	2028
6	Faisalabad	2x250	2022
7	Faisalabad	4x19	2022
8	Faisalabad	1x134	2025
9	Lakhra	2x30	2026
10	Kot Addu	1x251 and 3x247 and 336	2037
11	Hubco	4x300	2038
12	Kohinoor	9x13.8	2038
13	Aes	2x350	2039
14	Habib Coastal	1x126	2040
15	Rousch	1x395	2039
16	Saba Power	1x123	2040

3. RESEARCH METHODOLOGY

The research flow diagram of this novel study is given in Figure 1 and structure of LEAP model depicts in Figure 2. This energy plan is based on harnessing domestic energy sources for power generation to meet energy demand of Pakistan for the period 2020 to 2040 under the GPS.

Country is blessed with fossil assets and as well as with renewable energy assets. In this study, RLNG, hydro, coal, natural gas, nuclear, furnace oil and renewable (wind, solar, biomass) sources are considered for power production. In transformation module of LEAP, net energy generation capacity and energy production units of each energy resource for based year 2020 are considered as input to LEAP model for forecasting energy mix of Pakistan from 2020 to 2040. Efficiency, lifetime and maximum availability factors of energy harnessing technologies are also considered [31], [32] as input to LEAP model in estimating clean energy production. CO_2 emissions of fossil fuels are also used as input to LEAP model for estimating the future growth of CO_2 emissions from 2020 to 2040 in Pakistan. In energy demand analysis module, the key input parameters are population, past energy consumption from 2001 to 2020, total number of households in the country, transmission and distribution losses, total Gross Domestic Product (GDP) and their growth rates [19]. GDP, population, and number of households are directly linked with energy demand. If these parameters are increased by 20% then energy demand will increase by 43.6% and vice versa [33], [34].

Energy demand module and energy transformation module in LEAP are used to forecast future energy demand and production of Pakistan under the GPS. GPS present results under the energy policies of PG named Integrated Generation Capacity Expansion Planning (IGCEP) in 2018 and 2021, respectively.

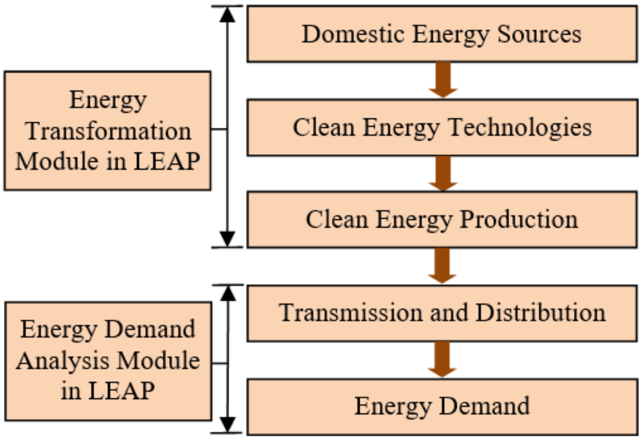

Fig. 1. Research flow diagram.

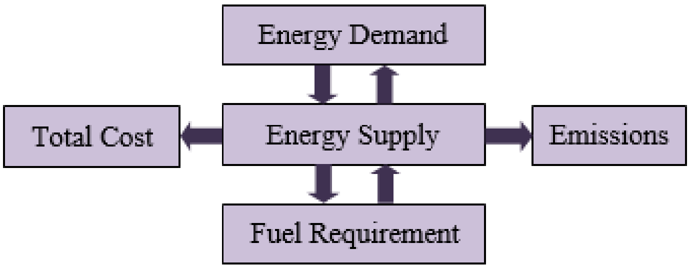

Fig. 2. Structure of LEAP model.

4. RESULTS AND DISCUSSION

4.1 Results of Future Energy Demand and Production Forecasting from 2020 to 2040

Energy demand module in LEAP forecasted future energy consumption pattern under GPS for the period 2020 to 2040 as shown in Figure 3. Domestic sector will consume greater energy throughout the study period with a growth rate of 6.2%. Increment in population and number of households in the country resulted in greater need of energy in domestic sector. Energy required in agriculture sector will also increase after 2030 with growth rate of 6.2%. A slightly decrement is seen in energy demand of industrial and commercial sectors till 2036 and then increases slowly till 2040. The growth rate of industrial and commercial sectors is 8% and 11%, respectively.

Energy transformation module in LEAP forecasted energy production under GPS for the period 2020 to 2040 as shown in Figure 4. PG has planned to harness maximum energy from coal through cleaner technologies such as IGCCT (Integrated Gasification Combined Cycle Technology) and CFBCT (Circulating Fluidized Bed Combustion Technology) and as this source is available in an abundant capacity in Pakistan. Hydro potential is also high in northern areas of Pakistan as this source produces clean energy. The growth rate of coal and hydro source in energy production for the years 2026, 2033 and 2040 are 18.4%, 16.9%, 42.1% and 31.4%, 47.1%, 33.3%, respectively. Furnace oil produces negligible energy throughout the study period as PG denied to import furnace oil from Iran. Nuclear, natural gas and RLNG plants are also contributed in energy production but with lower growth rates of 3.5%, 15% and 1.7%. The dependency of PG on the renewable (wind, solar, biomass) sources are also lesser because the cost of these plants are high and have low energy production efficiencies. The growth rate of renewable sources in energy production is 13%. Comparison of energy production and energy demand is shown in Figure 5. Energy demand and production for the years 2030 and 2040 are 135.3 TWh, 256 TWh and 250.9 TWh, 448.8 TWh, respectively. Energy production is much greater than energy demand which can help PG to promote the development of industries in the country and manages economy in a sustainable way through sustainable energy production in Pakistan.

4.2 Future Energy Mix Comparison and Assessment of CO_2 Emissions

Future energy mix comparison for Pakistan is given in Figure 6. The ratio of fossil fuels in energy mix is greater in all years. Presently, 60% to 65% fossil assets are dominant and all these resources are imported from Iran, Malaysia, Iraq, and Indonesia on high cost. PG planned to implement energy projects based on the domestic energy assets and facilitate the development of clean energy harnessing technologies. Contribution of renewables (hydro, solar, wind, biomass) and coal power plants are increasing continuously whereas the contribution of furnace oil, nuclear, natural gas, and RLNG in energy mix are decreasing drastically from

2020 to 2040. In this regard, the future CO_2 emissions are also forecasted on LEAP under the GPS as shown in Figure 7. CO_2 emissions increases at a growth rate of 11% from 2020 to 2040 as PG planned to harness maximum energy from coal reserves in Pakistan through cleaner technologies. CO_2 emissions will be greater in future because share of renewable sources will be decreased. Only coal resource will be utilized to fulfill maximum energy demand in the country.

4.3 Cost Analysis of the Future Energy Projects

In this study, input parameters of total system cost is expressed in term of Net Present Value (NPV) which includes fixed O&M (operation and maintenance), capital cost, and variable O&M costs as given in Table 5 at discounted rates of 4%, 8%, and 12%. The total cost of the project is shown in Figure 8.

In light of above discussion, it is notified that the PG will deploy many non-renewable energy source based power plants based which pollute the environment. Therefore, it is necessary to develop decarbonizing strategies and complementarities for the Pakistan's energy sector for meeting Paris Climate Agreement. Section 5 is presented the main strategies and complementarities for decarbonization of energy sector.

Table 5. Fuel wise capital, fixed and variable cost.

	Capital Cost (Million USD per MW)	Fixed Cost (Thousands USD per MW)	Variable Cost (USD per MWh)
Furnace Oil	1.16	26.21	8.52
Renewable	10	175.31	5.42
Nuclear	5.71	96.27	2.20
Natural Gas	0.6	7.27	10.70
Coal	4.2	32.18	4.61
Hydro	7	94.11	7.88
RLNG	1	15.86	3.30

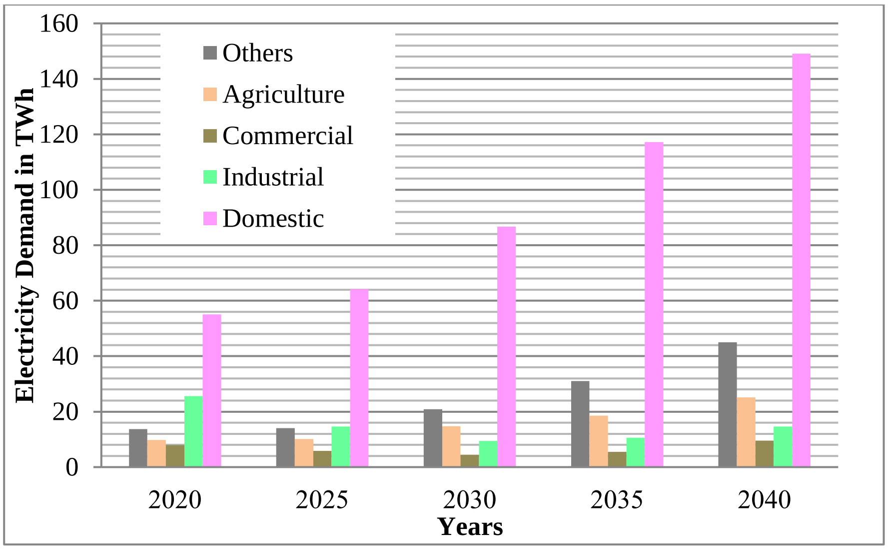

Fig. 3. Sector wise future electricity demand pattern.

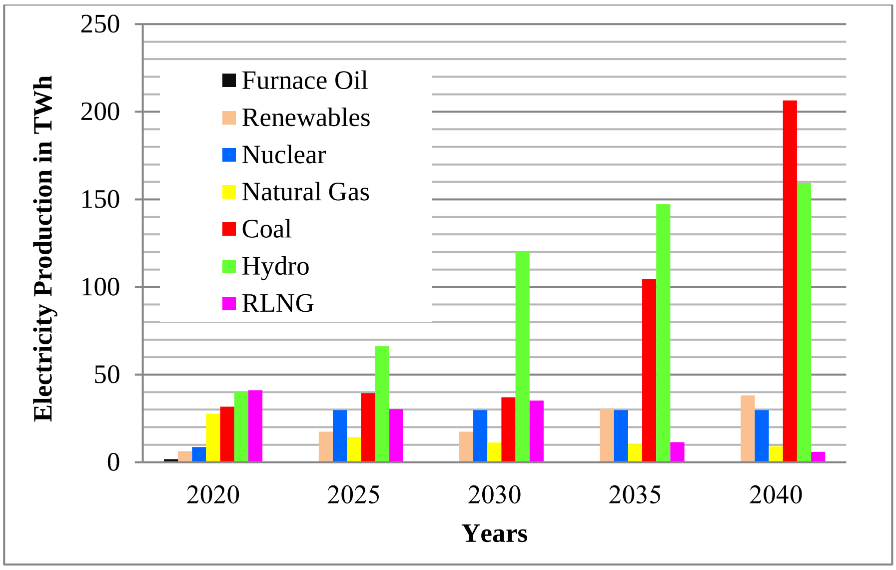

Fig. 4. Source wise future electricity production pattern.

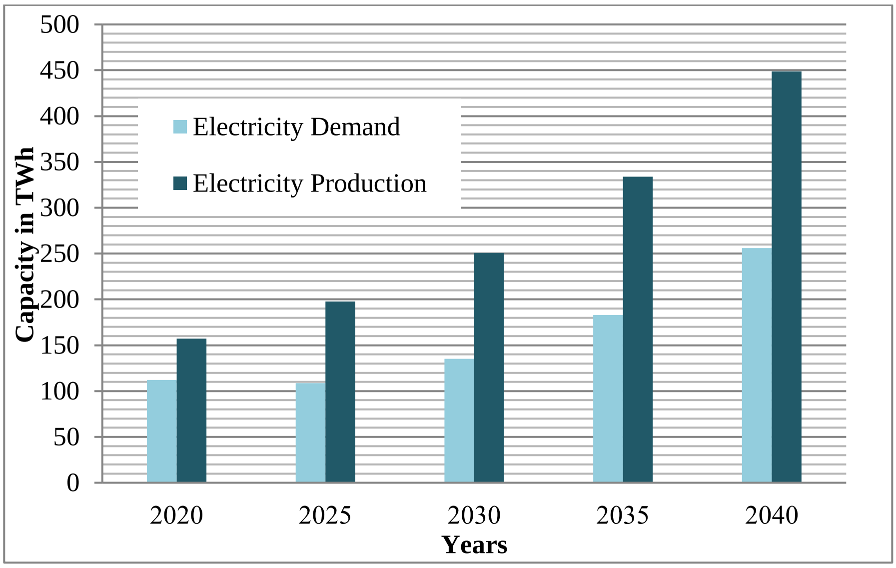

Fig. 5. Comparison of future electricity demand and production pattern.

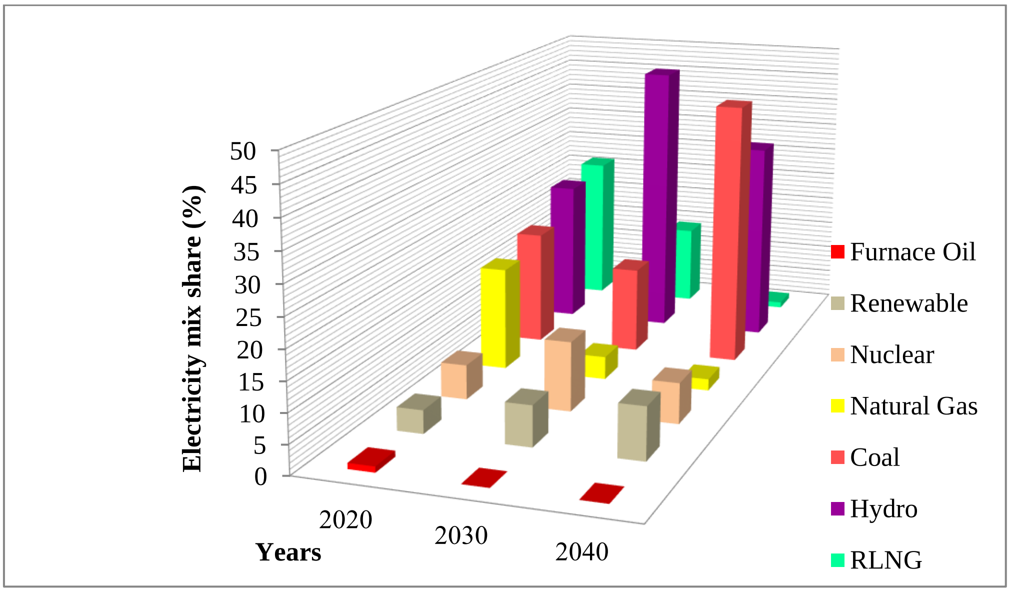

Fig. 6. Electricity mix comparison for years 2020, 2030 and 2040.

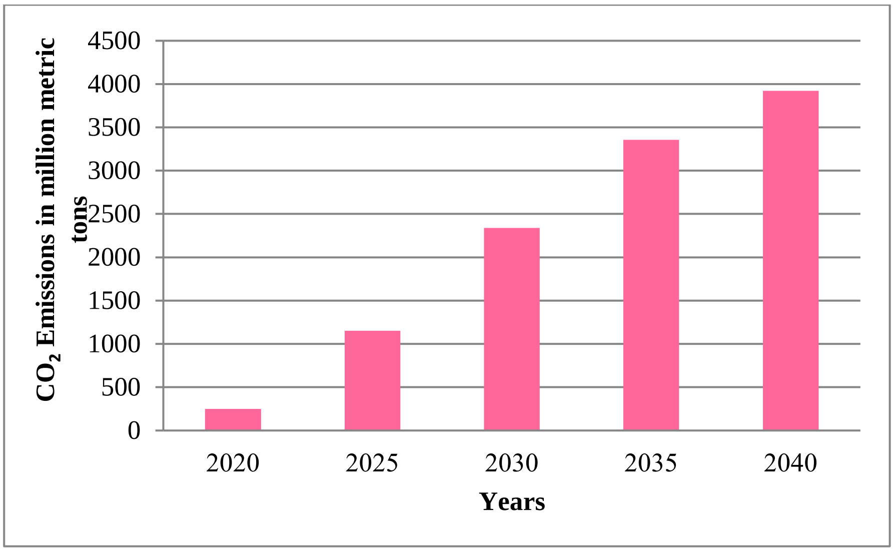

Fig. 7. CO_2 emissions forecasting from 2020 to 2040.

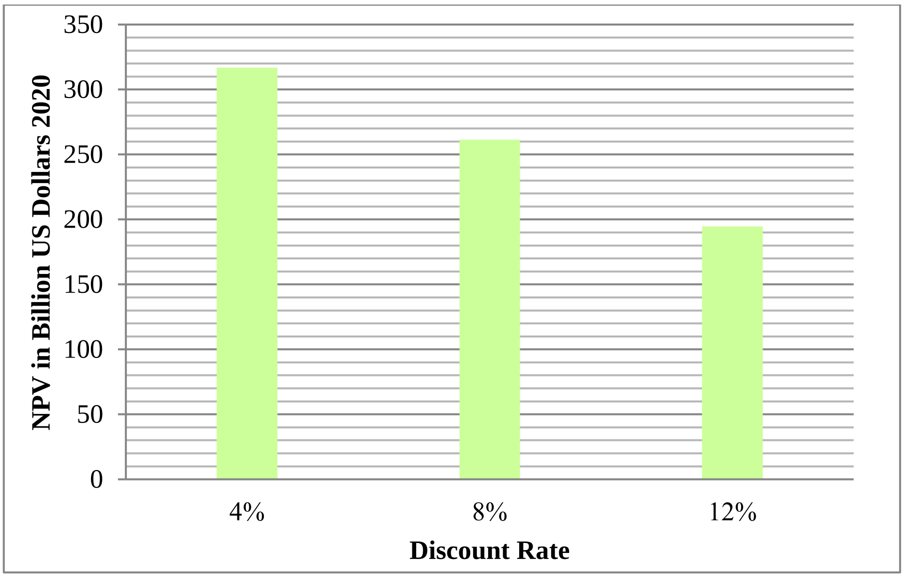

Fig. 8. NPV of the energy projects at discounted rate of 4%, 8% and 12%.

5. DECARBONIZATION STRATEGIES AND COMPLEMENTARITIES FOR THE PAKISTAN's ENERGY SECTOR

A decarbonization process has been in progress in the power sector in many nations worldwide. The well-set norms of the energy sector are now facing a model shift from fossilized to defossilized energy generation. The defossilized energy system facilitates the deployment of smart grid which helps to increase the share of renewable sources in energy mix by decreasing the dependence on fossil fuels. Smart grid technique uses the digital technologies and facilitates business models like energy trading. The defossilized energy system covers four domains:

1. Clean and sustainable energy supply based on renewable sources.
2. Carbon capture, utilization and storage facility.
3. Energy storage facility.
4. Other important options like sector coupling, network interconnection, demand side management and supply response.

Multiple technologies need to combine to achieve total decarbonization and the mix of available alternative varies from country to country due to local conditions, thus erasing the chance of one over-bearing solution. Technologies may be required for smooth defossilized energy system and coal must be phased out the earliest of all energy sources considering its contribution to carbon content and the same must happen with natural gas. The renewable and sustainable energy niche is dynamic and ever changing, regular assessments must be made of objectives and processes to allow any newly emerging technologies to take their share in the transition from fossilized to defosilized energy system.

Though many regional and world-wide policies focus on electrifying energy systems, electrification must go along with decarbonization. We should not underestimate potential of energy efficiency in the chain of electricity, and moreover, adopt a unified approach across sectors and energy pathways to effectively address climate change. Any technology used in this undertaking must be fully researched for any unwanted side effects to avoid a repeat of another disastrous global situation.

There are near limitless challenges in the decarbonization process of an entire global system, thus it is important to follow a unified approach the world-over. There is an intricate interconnectivity in the pursuance of any one or more objectives, and any action used in one objective can damage another goal, while others may achieve several goals with a single action. The power grid, for example, represents an exceedingly complex system that must remain in operation efficiently despite going through the greatest change in energy history. It will take much more than a single decarbonization policy or technology to fully reverse or limit the power grid's effect on global warming and many policies and technologies must be used in symphony to smoothly transition grid without causing a ripple effect to the rest of the system. To follow unified approach, number of complementarities is required for handling the energy system complexities:

1. Complementarities of variable renewable energy sources: Most sources of renewable energy are very dynamic, their availability shifting all the time. Solar is available only half the day. Wind can drop, reverse, or slow at any time. Tides change depending on the time of year. However, all randomness has a base in patterns, and digital grid systems are used to operate energy systems exactly when it is most efficient.
2. Complementarities among zero-carbon technologies: A common example is that of zero-carbon electric cars, which need an electric infrastructure to drive them.
3. Complementarities of public and private investments: As with any business, the energy grid consists of shares that are privately and publicly owned, causing a certain disruption in effective operation. The system needs time and research to fully appreciate the diversity of options and collaborative actions that can result from this relationship of private and public share of the system.
4. Complementarities of natural and engineered systems: In addition to not producing any additional carbon, we must recapture the carbon we have released through biological methods. Replanting forest and vegetation, protecting present biodiversity, and finding ways to intertwine biological replantation and human infrastructure are all key to this.
5. Complementarities of mitigation and adaptation: Adapting human systems and processes to mitigation strategies might make the roll-out of both objectives faster. Restoring vegetation and biodiversity would help mitigate storm surges, make for more efficient food growth, and trap carbon, helping the growth of both objectives.
6. Complementarities of centralized and decentralized solutions: Those sources of sustainable energy available in one area are not necessarily available in another, and thus would require specific research and design to make a system that fits each unique location.
7. Complementarities of actions and strategies in different geographies: Decarbonization strategies must also change depending on the region that they are applied in. After all, the geographic, geologic, political, and demographic aspects of the western world are completely different to those of North Africa, the Middle East, and South Asia. Urban populations already have access to all amenities, while rural areas struggle to provide even water and electricity. They cannot follow the game plan, otherwise they would be doomed to a slow and unforgiving process.
8. Complementarities of Research and Development (R&D) activities: R&D must a top priority of research organizations and schools and must be given monetary support publicly and privately. The goal of any R&D undertaking should be the development of decarbonizing technologies that feed the approved models of bringing carbon and other emissions under control and reverse the process of global warming, as well as keeping the drive behind the movement alive and not let it lapse into a static and unrewarding process.

6. POLICY RECOMMENDATIONS

In this passage, authors narrow down many of the important strategies for policy proposals:

1. Zero-carbon electricity: An electricity system with zero emission production.
2. Electrification of end uses: Converting existing product fuels to electricity can remove the need for fossil fuels to drive these products.
3. Green synthetic fuels: The development of green and more environmentally friendly fuels to meet the demands of specialized industries and products that cannot be fulfilled by electric supply.
4. Smart power grids: Power grids that are optimized to use many different sources of green electricity and provide to a large variety to consumers in every sector to ensure a large supply of reliable energy.
5. Materials efficiency: Improved matter systems like "reuse, reduce, and recycle," to drive the efficiency and maximum life and use of any material while reducing the need for additional material to be procured.
6. Sustainable land use: Optimizing land use so minimum input results in maximum output and land is used in many ways to reduce the global human footprint, especially agriculturally, where much carbon emissions exist despite technologies existing to make the sector streamlined.

7. CONCLUSION

The aim of this paper is to create balance between future energy production and energy demand to alleviate energy crises in Pakistan. GPS is developed using LEAP model to forecast future energy production, energy demand and total CO_2 emissions. This study considered economical, technological, and environmental aspects in the energy demand analysis and energy transformation module of LEAP. It is concluded that the energy demand and production for the year 2030 is 135.3 TWh and 250.9 TWh whereas for 2040, the energy demand and production is 256 TWh and 448.8 TWh respectively. Presently, 60% to 65% fossil fuels are used, and all these resources are imported from Iran, Malaysia, Iraq, and Indonesia on high cost. In future, by the year 2040, the share of fossil fuels will reduce by 20% and share of renewable will increase by 15% in total energy mix of Pakistan. CO_2 emissions increase at a slower growth rate of 11% from 2020 to 2040 as Pakistan has started harnessing energy from domestic fossil assets through cleaner technologies and reduce dependency on imported fossil assets. Cost of future energy generation projects are assessed in terms of net present value at discount rate of 4%, 8% and 12%. It is found that energy projects cost will be 50% less at discount rate of 8%.

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