Decarbonization of Electricity Sector of Pakistan — An Application of Times Energy Model

Gordhan Das Valasai, Nayyar Hussain Mirjat, Muhammad Aslam Uqaili, Hafeez Ur Rahman Memon, Saleem Raza Samoo, and Khanji Harijan

Abstract—**This study explores the decarbonization potential and economic analysis of the power generation sector of Pakistan. PakistanTIMES energy model has been developed using TIMES energy model with focus on limiting the CO_2 emissions under two alternative scenarios CEC10 and CEC20. Various power generation technologies; their cost and performance characteristics, fossil fuels and renewable energy resources availability, potential and costs, a number of assumptions, and suitable modelling parameters have been considered for the study period 2014-2033. BASE scenario results of the model warrants that Pakistan needs to invest to the tune of US$ (2014) 29.2 billion to ensure consistent electricity supply during the study period. It is also estimated that CO_2 emissions will reach 171 million tonnes by year 2033. On other hand, alternative scenarios CEC10 and CEC20 shall result 153 and 136 million tonnes of CO_2 emissions respectively by the end of study period. The investment cost estimated by the model for CEC10 and CEC20 scenarios are to the tune of 30 and 34 billion US$ respectively. These results suggest that Pakistan can achieve the decarbonization of power generation sector in the range of 10-20 % gradually towards year 2033 with additional system costs of 1-5 billion US$.**

Index Terms—**Decarbonization, TIMES energy model, Pakistan electricity sector, GHG Emissions, investment cost analysis.**

I. Introduction

Increased burning of fossil fuels (Coal, oil, and gas) to meet the energy demand has not only resulted in the Greenhouse Gases (GHGs) emissions but also caused the global warming leading to climate change. This situation demands for exploring alternatives to fossil fuels for achieving targets of energy supply, security, and sustainability [1]. In order to achieve these targets altogether, a major shift is required in the use of primary energy sources along with improvements in energy efficiency and conservation. Moreover, in the coming decades, a major reduction in GHG emissions will be required in order to limit the global mean temperature increase to 2^{o}C [2]. The scientific consensus has been that GHG emissions reductions on the order of 80 percent from 1990 levels are necessary to avoid dangerous temperature increases. Under these circumstances the developing countries are under heavy pressure of mitigating and adapting the climatic consequences on one hand and meet the growing demand of electricity on the other hand.

Pakistan has recently submitted its Intended Nationally Determined Contributions (Pak-INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). Along with its Vision 2025, Pakistan has given its roadmap toward the sustainable development with commitment to the issue of global climate change in the national level energy policies. As a result Pakistan faced criticism by the other signatories and in the media on submission of IDNC without any concrete pledge to mitigate or cap the GHG emissions [3].

Given the condition that Pakistan is not only facing the problems of electricity shortages but also the economic and environmental issues as well as, with need to supply electricity at minimal costs. The electricity shortage ranges between 4,800 and 7,000 megawatts (MW) [4]. Although Pakistan being stated as a developing country having lower contribution to global GHG emissions but it is highly affected by the droughts, floods, and other climate related problems.

In this context, the government has been taking various measures, including partial restructuring of the electricity sector under guidelines from international financing institutes. The role of policy makers at this stage is crucial for not only assessing and reviewing the current strategies to minimize electricity supply and demand gap, but also need to develop future strategies, ensuring affordable electricity with efficient generation, transmission and distribution towards sustainable development in the country.

The current research focuses on how Pakistan can contribute achieving decarbonization of the power generation sector of Pakistan on the basis of availability of energy resources, costs, and emissions.

II. Methodology

TIMES is acronym of The Integrated MARKAL-EFOM

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(Energy Flow Optimization Model) System which was introduced in 1998. It is bottom-up, dynamic, partial equilibrium, linear programming model. It was developed by the International Energy Agency (IEA,) under Energy Technology Systems Analysis Program (ETSAP). The model determines optimal energy supply mix (generation based on type and fuel) to meet the energy requirements while considering the features of alternative electricity generation technologies, energy supply economics, environmental impacts and given set of energy prices and limitations.

III. PAKISTAN TIMES MODEL DEVELOPMENT

The PakistanTIMES model developed under this study is based on the techno-economic and performance characteristics of generation technologies and energy resources. The government policy and plan of Vision 2025 along with several assumptions and modelling parameters are also used. The input data required for the model are:

- Electricity demand
- Availability of energy resources
- Costs and performance characteristics of the power generation technologies.

The relationship among these three is held together by the data structure of AnswerTIMES framework. Details of the data sources and its handling are explained in the following section.

TIMES is a highly data-intensive, technology rich model which works on the optimization method for economics of the energy systems. It needs a variety of data parameters to describe each element (i.e. process, commodity, and trade) of the Reference Energy System (RES).

TABLE I: ELECTRICITY DEMAND FORECAST DATA FOR 2014-2033

Year	Electricity Demand (in GWh)
2014	105,640
2015	113,584
2020	163,390
2025	235,002
2030	338,030
2033	420,392

IV. DATA SOURCES

The TIMES energy model is a highly data intensive model, requires a range of data on the resources, technologies, their cost and performance indicators along with assumptions and constraints and bounds. The current study uses electricity demand forecasted by Harijan [5] for the modelling period (2014-2033) after comparison with past consumption and with other related studies on the subject as shown in Table I.

TABLE II: RESERVES TO PRODUCTION (R/P) RATIO OF FOSSIL FUEL

	Oil	Natural Gas	Coal
Reserves (MTOE)	49.7	411.6	7,775
Production (MTOE)	4.2	30.9	1.5
R/P ratio (Years)	11.8	13.2	~5050
World Average R/P Ratio (Years)	40	59	110

The data on the energy resources and reserves availability is collected from various government publications and documents available publicly. According to Hydrocarbon Development Institute of Pakistan (HDIP), the rate of consumption of oil is so high that with the current rate of production, indigenous oil reserves will be exhausted by 2025, whereas the indigenous resources of natural gas will run out by 2030 unless new natural gas and oil reserves are to be explored, as depicted in Table II [6].

Table III describes the potential of Wind, Solar and Hydropower in Pakistan as estimated by the Alternative Energy Development Board (AEDB) of Government of Pakistan [7, 8].

TABLE III: POTENTIAL OF RENEWABLE ENERGY SOURCES

Source	Potential
Wind Energy	42,000 MW
Solar Energy	535,000 GWh
Hydropower	41,700 MW

The reliable country specific data for Pakistan on costs and performance characteristics of power generation technologies is very difficult to find, as per literature survey and academia level research efforts in the past. The cost related data depends upon the local conditions and some technical parameters on the climatic conditions. Due to non-availability of reliable data for Pakistan, EIA [9] data source is used for cost and performance related data and other references [7], [8], [10]-[13] for the remaining data on the power generation technologies [9]. Extensive literature reviews of past researches and official documents was carried out to collect the required data for Pakistan [14]-[31]. The techno-economic and performance characteristics of the power generation technologies, adapted from the literature is given in Table IV.

TABLE IV: TECHNO-ECONOMIC CHARACTERISTICS OF THE POWER GENERATION TECHNOLOGIES

	Capital Cost US$/MW	FO&M US$/MW	Activity Cost US$/MWh	Efficiency (%)	Annual Availability (%0	Lifetime (Years)	TLIFE (Years)	CO_2
BAGAS	3,280,000	65,600	150,000	0.30	0.5	2	20	5277.8
BIOMC	1,786,410	74,430	5,300,000	0.23	0.85	3	30	109558
HCOAL	3,303,720	42,898	1,413,600	0.37	0.75	4	40	96235
HYDRO	2,178,540	60,637	-	0.34	0.70	4	50	-
HYDRUNOF	1,146,500	36,000	-	0.34	0.70	2	60	-
LIGIN	2,913,840	33,376	1,413,600	0.40	0.75	3	40	99800
NGCC	1,211,820	13,851	638,000	0.47	0.70	3	30	55781
NGTOC	808,260	13,441	1,094,400	0.32	0.70	2	30	55781
NUCFUEL	5,131,140	99,864	148,200	0.34	0.85	6	40	-
OILFUR	1,368,000	19,289	763,800	0.40	0.70	3	30	76540
SOLARE	7,284,600	12,962	-	0.34	0.18	-	20	-
WIND_A	2,850,000	72,094	-	0.31	0.26	2	20	-

TABLE V: SCALING FACTOR PARAMETERS

	EU27 (average)	Pakistan
$\mathbf{SF_{ext}}$	$SF_{ext,EU}$	$SF_{ext,T}$
$\mathbf{P_{den}}$	179	235
GDP	34423	4476

Regarding the data on environmental externalities of power generation, the literature review suggests that only a few developed countries have managed to estimate the external costs of power generation [32]-[34]. Some of the researchers adapted the external costs data of developed countries by using appropriate scaling factor ($\mathbf{SF_{ext}}$) for another country [35], [36]. Therefore, current study incorporates the external costs of power generation technologies estimated by Cost Assessment for Sustainable Energy Markets (CASES) for 27 countries of the European

Union (EU) [34]. Similarly, the external costs for Pakistan are calculated by using a comparative scaling factor between EU27 countries and Pakistan based on purchasing power parity (PPP) GDP and population density (number of persons per square kilometre). GDP and population density parameters of referred study and Pakistan are given in Table V.

$$SF_{ext,T} = \frac{P_{den,T} \times GDP_T}{P_{den,EU} \times GDP_{EU}} = 0.171$$

Based on above equation, the external costs related to power generation for Pakistan are adapted form CASES study by using the scaling factor of 0.171, as shown in Fig. 1.

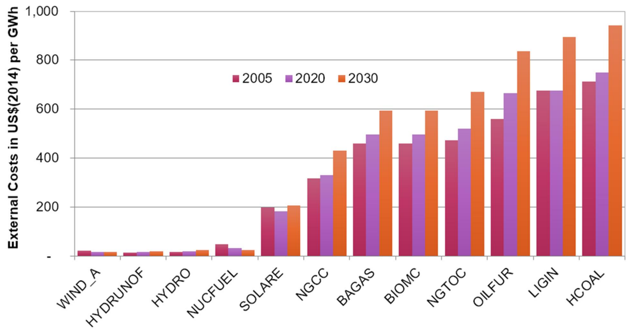

Fig. 1. External costs of power generation technologies for Pakistan.

V. Results & Discussion

BASE scenario; developed using AnswerTIMES energy modelling framework provides the fuel mix and technology for electricity generation in Pakistan during modelling period 2014-2033 as per existing government policies, i.e. calibration of base year in the model. This modelling exercise has been named as PakistanTIMES energy model. BASE scenario covers the existing fuel mix and relevant technologies which has been calibrated for first year of the modelling period. This scenario satisfies the initial condition of meeting electricity demand and serves as a reference scenario for developing two alternative scenarios envisaged under the emission reduction scenarios, CEC10 and CEC20 based on the same modelling framework. Following sections provides detailed results of these scenarios for the installed generation capacity, electricity generation by different fuels and technologies, CO_2 emissions, total systems costs, and real system costs estimates.

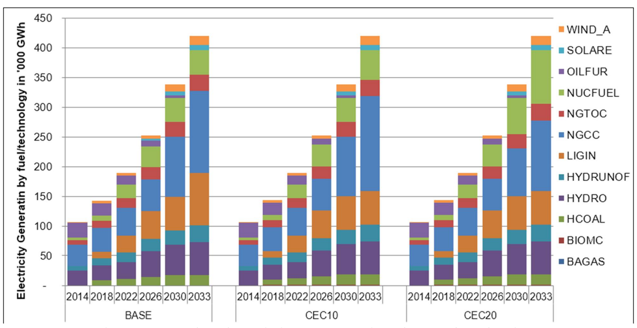

Fig. 2. Yearly electricity generation by technologies.

A. CEC10 Scenario

A 10% CO_2 reduction target was introduced under CEC10 scenario directly affected the electricity generation from fossil fuel based generation to lower carbon emitting conversion technologies and nuclear electricity generation. Compared with BASE scenario, it can be seen in Fig. 2 that the share of LIGIN is reduced from 21% to 13% in CEC10 scenario. Similarly, share of NGCC and NUCFUEL is increased from 33% and 10% in BASE scenario to 38% and 12% respectively in the CEC10 scenario.

Similarly, the share of low carbon emitting conversion technologies has shown growth in installed generation capacity over the modelling period as shown in Fig. 3. Model does not show any major change in case of SOLAR, WIND_A, HYDRO based installed capacity, on comparing with the BASE scenario.

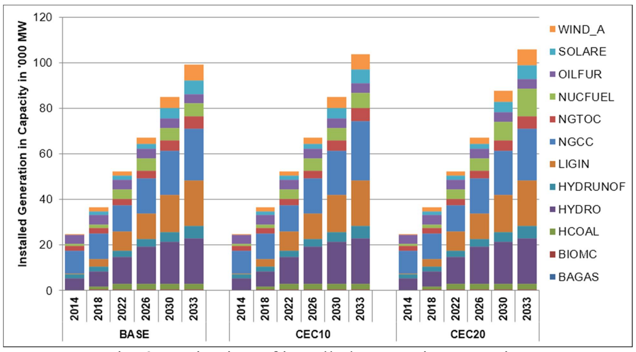

Fig. 3. Projection of installed generation capacity.

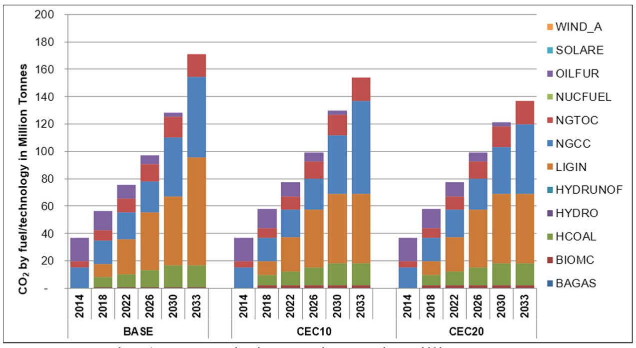

Fig. 4. CO_2 emissions estimates in million tonnes.

As the CEC10 modelling scenario is constrained by a 10% cap on the CO_2 emissions gradually by the year 2033, the results also satisfy cap of 10% reduction in emissions by giving preference to lower carbon power generation technologies, as shown in Fig. 4. The major share of CO_2 emission during the modelling period (2014-2033) is from the coal and natural gas based electricity generation. The model gives preference to natural gas than coal to satisfy the 10% emission cap on CO_2 emission.

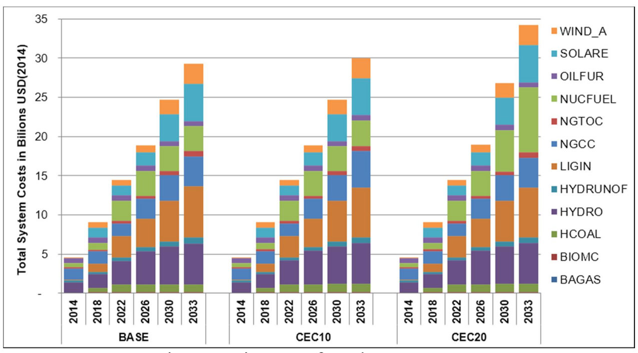

Fig. 5. Estimates of total system costs.

The PakistanTIMES model estimates that the electricity generation sector in Pakistan, under CEC10 scenario, will require an estimated amount of US$ (2014) 30 billion (i.e. 6.6 times the total system cost in year 2014) by the year 2033 as shown in Fig. 5.

B. CEC20 Scenario

Under CEC20 scenario, a cap of 20% on CO_2 emissions gradually by year 2033 was introduced in the model. This constraint on CO_2 emissions resulted in priority given to NGCC and NUCFUEL based electricity than to LIGIN. As it can be seen in Fig. 2 that the share of OILFUR is reduced from 24% in year 2014 to 0% in year 2033 and that of NUCFUEL increased from 4% in year 2014 to a 21% in year 2033. On the other hand, share of HYDRO is decreased from 23% in year 2014 to 13% in year 2033, due to introduction of more nuclear and renewables, and government's plan to prefer indigenous coal.

The model estimates the growth of installed generation capacity from a 24,600 MW in year 2014 to 103,800 MW in year 2033 under CEC20 BASE scenario, with major contribution from NGCC, HYDRO, LIGIN, NUCFUEL and increasing share of SOLARE and WIND_A as shown in Fig. 3. The increased share of SOLARE and WIND_A is due to government's ambitious implementation of Vision 2025.

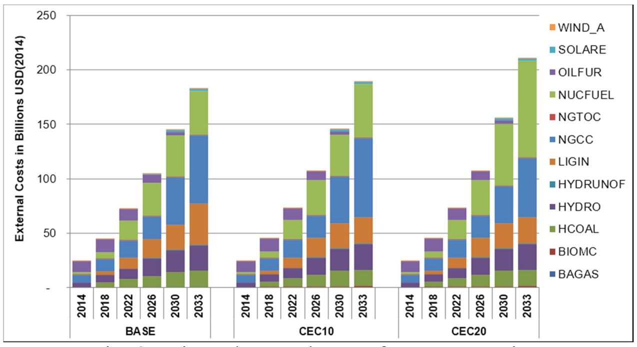

Fig. 6. Estimated external costs of power generation.

The CEC20 modelling scenario is based on the gradual cap of 20% on CO_2 emissions by year 2033. As shown in Fig. 4, the model satisfies this initial bound of CO_2 emissions constraint by preferring the lower carbon power generation technologies. The gradual reduction in CO_2 emissions is majorly achieved by alternating the OILFUR and LIGIN by NUCFUEL, SOLARE, and WIND_A.

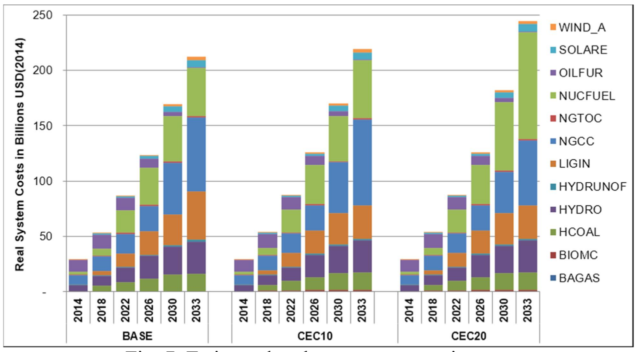

Fig. 7. Estimated real system costs estimates.

The PakistanTIMES model estimates that the electricity generation sector in Pakistan, under CEC20 scenario, will require an estimated amount of US$ (2014) 34.2 billion (i.e. 7.5 times the total system cost in year 2014) by the year 2033 as shown in Fig. 5. Whereas, the estimated external costs for power generation are shown in Fig. 6.

C. Real System Costs

The sum of total system costs and the external costs of power generation estimated under the current study are referred as the Real System Costs (RSCs). The RSCs of CEC10 and CE20 scenarios are 3.1 and 13.2 percent higher than that of BASE scenario, in year 2033. The Real System Cost for BASE, CEC10 and CEC20 are found to be US$ 212, 219 and 244 billion respectively in the end year as shown in the Fig. 7.

VI. Conclusion

The PakistanTIMES energy model was developed under current study for the period 2014-2033 to meet the electricity demand in the country. Initially the BASE scenario was calibrated for year 2014 and alternative scenarios namely, CEC10 and CEC20 scenarios to reduce the CO_2 emission gradually by 10% and 20% respectively in the end year. The model results suggest that in order to achieve CO_2 reduction of 10% by end year; the total system costs to increase by 2.5%. Whereas, the reduction of 20 percent emissions will result in 16.9% increase in total system costs.

It is pertinent to mention that enhanced strict regulation on environmental emissions may also push developing countries like Pakistan to consider the external costs in overall generation costs in future. Pakistan has already committed under INDC to cap GHG emissions to a certain extent, this study lays an important foundation in this context.

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