Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48 (4) 775-778 (2016)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Assessment of Renewable Energy for Electricity Generation: Using Pakistan TIMES Energy Model

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Received 13th June 2015 and Revised 28rd October 2016

Abstract: This paper analyses the feasibility of renewable energy resources in the fuel mix for electricity generation in Pakistan to achieve sustainable economic growth, energy security by minimizing environmental emissions as well as considering external costs. TIMES energy modelling framework have been used to develop three supply side scenarios viz BASE, REN50 and REN60. The study incorporated the environmental externalities of power generation to neutralize the edge to fossil fuel and nuclear fuel based power plants. Model results of BASE scenario were compared with two alternative scenarios of gradually increased sharing of renewable energy in total power generation by 50%in REN50 and 60% in REN60 for modelling period (2033). The simulation results suggest that when considering environmental emission and external costs in particular, both the REN50 and REN60 scenarios are more feasible and sustainable electricity generation scenario providing policy makers an insight to consider more renewable energy sources in long term electricity generation planning.

Keywords: Electricity Generation, Renewables, Energy Policy, Environmental Externalities

1. INTRODUCTION

This paper analyses the integration of renewable energy for power generation in Pakistan in order to achieve sustainable economic growth along with energy security and environmental goals in parallel with achieving a certain level of carbon mitigation using TIMES energy modelling framework. This study incorporated the environmental externalities of power generation to neutralize the edge generally benefitted the fossil fuel based power plants. The paper also provides better insights to the policy makers toward understanding of the future possible fuel mix of power generation to benefit the decision makers in the medium to long-term future.

In the past, a few studies have been conducted to optimize the future energy mix in Pakistan. One of these studies was carried out by the Ministry of Planning and Development, Government of Pakistan on Integrated Energy Model (Pak-IEM). The Pak-IEM examined the power generation technologies, availability of the energy resources, constraints and options, capital trade-offs, economic growth targets and the government policies.Another related study was executed by the National Transmission and Despatch Company (NTDC) of Pakistan. The National Power System Expansion Plan (NPSEP) NSEP was intended at developing a plan to utilize the indigenous hydroelectric potential along with establishment of thermal, nuclear and renewable energy resources to meet the forecasted electricity demand over the futurealong with classifying the new electricity generation facilities; in parallel with transmission and distribution network improvement. The NPSEP also recommended to update the feasibility reports of hydropower and should be implemented for accomplishing the least cost power mix plan. The plan also identified the negative impacts of natural gas shortages in the country, which could be minimized by devising a plan to encourage the natural gas resources in the country and additionally construction of natural gas import pipelines as well as with LNG import.

Various other studies conducted for other economies like Roth and Ambs, Becker, Soloveitchik , Rentizelas and Georgakellos , Kannan and Strachan , concluded that internalizing the external costs of generation technologies would increase the possibilities to evolve the least cost resource from the societal viewpoint. The external costs consideration leaves huge impact on the power generation system. The internalization of external costs proves to be appropriate policy for emission mitigation of capacity expansion planning. However, researchers have used the adapted data, due to limited availability of data on the environmental damage costs, especially for the developing countries.

Coupled with limitation of data availability like national level environmental cost power generation and

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lack of figures related to import of power generation related equipment, the current study uses the relevant data from studies conducted for other countries; after adapting it for Pakistan.

The installed generation capacity in Pakistan increased from 6,400 MW in 1990 to 24,269 in 2014, i.e. a fourfold increase in the total capacity.

Fig.1shows the trend in installed generation capacity in the country since (1990). It is evident from **(Fig.2)** that the thermal and hydroelectric power plants are having a major share in total electricity generation. The widening gap between supply and demand may be named as a self-inflicted problem, an outcome of years' long poor policies and faulty management. It is evident from the series of compounded problems in the electricity sector that now there seems to be no immediate solution to the deepening crisis.

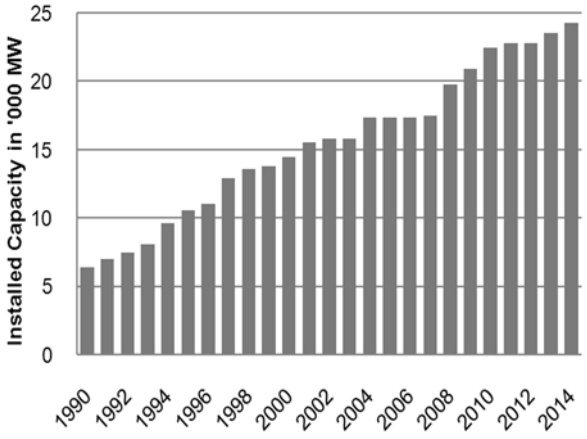


Fig.1: Trend in Installed Generation Capacity in Pakistan

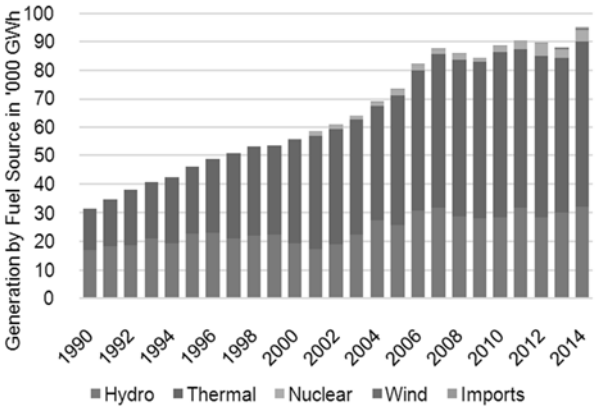


Fig.2: Trend in electricity generation by fuel source

2. METHODOLOGY

TIMES is acronym of The Integrated MARKAL-EFOM (Energy Flow Optimization Model) System which was introduced in 1998. It is bottom-up, dynamic, partial equilibrium, linear programming model. It was developed by IEA, under ETSAP (Energy Technology Systems Analysis Programme). Basic purpose of this model was to evaluate the national and regional energy systems and the impacts due to adaptation of new energy technologiesThe 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. The least-cost solution route starts from the selection of resources and transformation technologies which are based on their techno-economic parameters along with variety of constraints.

AnswerTIMES is a comprehensive modelling platform; which comprises a number of software working in series. This modelling framework is a set of data, fully describing the energy system under study. The objective function of the model is to minimize the net present value of the system and is given by (1):

$$NPV = \sum_{r=1}^{R} \sum_{y \epsilon YEARS} (1 + d_{r,y})^{REFYR-y} \times ANNCOST(r, y) \quad (1)$$

Where:
$NPV$is the net present value of the total cost for all regions i.e. the AnswerTIMES objective function;
$ANNCOST$is the total annual cost;
$d$is the general discount rate;
$REFYR$is the reference year for discounting;
$YEARS$is the set of years.

3. MODEL DEVELOPMENT

Linking techno-economic characteristics of power generation technologies the availability of resources for adequate electricity generation to meet the demand, PakistanTIMES Model was developed; based on a number of scenarios, assumptions, and modelling parameters. The modelling data can be categorized into three major groups; electricity demand, availability of energy resources, and costs and performance characteristics of the power generation technologies. The relationship among these three is held together by the data structure of AnswerTIMES framework.

3.1.1. Conventional Energy Sources

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 . According to an estimate less than 4% of probable oil reserves and 19% of gas reserves are measured, while just 1% of coal reserves are prove.

Table 1: Reserves to Production (R/P) ratio of fossil fuel reserves

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

3.1.2. Renewable Energy Sources

Over the last decade the wind power generation grew notably and is second highest renewable source of energy in the amount of electricity generation in the world [According to the Alternative Energy Development Board (AEDB) of Government of Pakistan, the estimated potential of wind power in the Gharo-Keti Bandar Wind Corridor in the coastal area of Sindh province is approximately 42,000 MW of gross resource as shown in**(Table 2),** however, currently wind power capacity is only 106 MW.

Table 2: Potential of Renewable Energy Sources in Pakistan

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

In Pakistan, the government has also plans to add a significant share of solar energy based electricity generation capacity in the country by the year (2030) The power generation using solar energy can be a competitive alternative to fossil fuels in the long run. This is further supported by the fact that solar energy potential ranges between 2.0-8.5 kWh/m^2 per day and sunshine hours 1500-3000 [30][29]. Currently, a 1,000 MW solar PV power plant is under construction at Bahawalpur, Pakistan under Quaid-e-Azam Solar Power (Pvt.) Limited.

Pakistan has huge resource potential of biomass for power generation in future. With current rate of production of agricultural residues and animal waste, it can be used to produce 535,000 GWh of electricity annually.Current hydroelectric power installed capacity in the country stands at 7,116 MW with increasing share of smaller runoff river power stations. However, the total hydroelectric potential is estimated to be 41,700MW, as such, only 17% of the potential is so far harnessed [32, 33].Diamer-Bhasha dam, which involves an estimated cost of US$ 15 billion in year 2015, increased from US$ 12 in year (2013). The first phase of Dasu Hydroelectric power project will add 2,160 MW to the installed capacity of the country

4. RESULTS AND 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. This modelling exercise has been named as PakistanTIMES energy model. BASE scenario takes into account 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 REN50, and REN60 using same modelling framework. The share of electricity generation using renewables has been increased two alternative scenario. The model simulation results for BASE, REN50, and REN60 scenarios using various fuels and technologies to meet the electricity demand during the modelling period 2014-2033 is illustrated in **(**

Fig. 3**).**

It is evident from

Fig. 3that natural gas, hydro, and coal based electricity generation shall have major share in total generation over the modelling period 2014-2033. The alternative electricity generation to reduced oil is projected to be wind 4%, solar PV 2%, nuclear 10%, and hard coal by 4%, and lignite by 21% in the year 2033. In the REN50 scenario, the share of WIND_A and SOLARE increased from 0% and 0% in the year 2014 to a 24% and 6% respectively in the year 2033. The REN60 is more renewable energy intensive scenario and under the given bounds the model increased the share of renewables gradually to 60% toward the year 2033. As shown in

Fig. 3 the share of WIND_A and SOLARE increased from 0% and 0% in the year 2014 to a 32%

and 7% respectively in the year 2033. Whereas, the share of NGCC and OILFUR based power generation reduced from 33% and 24% in the year 2014 to 10% and 0% in year 2033 respectively. Meanwhile, the share of HYDRO continues to decrease in scenario and share of HYDRUNOF remained same.

The CO_2 emissions under all three scenarios are significant. the results of CO_2 emissions under BASE, REN50, and REN60 scenarios. As expected the CO_2 emissions under REN50 and REN60 are much lower than those in BASE scenario due to increased share of renewable based electricity generation. It is observed that the major share in CO_2 emission in all three scenarios is contributed by LIGIN, HCOAL, and NGCC based power generation.

4. CONCLUSION

In this study we developed three electricity generation scenarios for Pakistan using Answer TIMES Modelling framework for the period 2013-2033 to meet the electricity demand of the country. The BASE scenarios is taken as the reference scenario following therein the existing electricity generation pattern and REN50 and REN50 scenarios which are rich with renewable energy resources for electricity generation. Owing to low availability of renewable energy based electricity generation units the required installed capacity is found to be higher both in REN50 and REN60 scenarios when compared with BASE scenario. The CO_2 emissions, however, are greatly lowboth in REN50 and REN60 scenarios compared to the BASE case suggesting REN50 and REN60 as of sustainable scenarios for the electricity generation. Further, the total system costs are estimated using the model and found to be lower in case of BASE scenario when compared with other two alternative scenarios mainly for more installed capacity in REN50 and REN60 to match lower availability of power plants based on renewable energy. As regards the external costs, obviously the BASE case costs are found higher compared to the REN50 and REN60 scenarios. Finally the Real System Costs were estimated i.e. summing up the total system costs and external costs of three scenarios of this study which suggest that REN50 and REN60 scenarios are feasible with BASE scenario costs estimated highest.

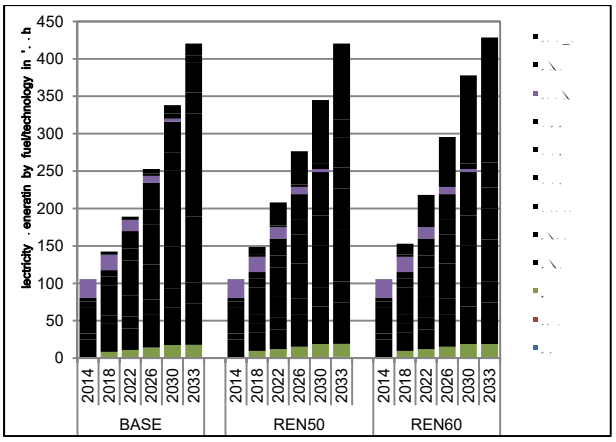


Fig. 3: Electricity generation by fuel types and technologies under different scenarios

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