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An Analysis of Energy Security Using the Partial Equilibrium Model: The Case of Pakistan

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1. INTRODUCTION

Restricting energy imports and total primary energy supply are the two direct policy options used for the improvement of energy security. Restricting energy imports directly reduce energy import dependency that leads to diversification of energy resources and ultimately enhances energy security while total energy supply reduction affects the energy security through the diversification of efficient technology mix and energy resources supply mix.

As energy is a vital element for sustained economic growth and development, therefore energy consumption is used as a basic indicator of people living standards. Due to technological and industrial development, the demand of energy in Pakistan is increasing more than the total primary energy supply; therefore, it is confronting the severe energy deficit today. So there should be a serious concern for the government about the energy security and should take enough actions for the development of indigenous alternative and renewable energy resources.

Energy security, particularly security of oil supply, has become a key political and economic issue in recent years. Energy security in simple words means the security of energy supply. From economic point of view, energy security refers to the provision of reliable and adequate supply of energy at reasonable prices in order to sustain economic growth.

Pakistan as an energy deficient country is facing the challenge of energy security. A few papers analysed this issue highlighting just the energy situation of the country, ignoring the analytical side of the issue. Sahir and Qureshi (2007) gave an overview of the energy security issues in the global and regional perspectives and depicted the specific implications and concerns for Pakistan. Moreover, the global and regional energy security is not vulnerable to shortage of energy resources but may be exposed to energy supply disruption and availability of tradable resources and threatened by growing terrorism and geopolitical conflicts.

Due to limited fossil fuel resources and poor economy, a huge portion of the population in Pakistan still have no access to modern day energy services such as electricity [see Mirza, *et al.* (2003); Mirza, *et al.* (2007a); Mirza, *et al.* (2007b)]. To

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overcome energy shortage, Pakistan should develop its indigenous fossil energy resources and alternative renewable resources like mini-hydro, solar and wind [see Mirza, *et al.* (2007a); Mirza, *et al.* (2007b)]. Pakistan has a vast potential of mini-hydro, solar and wind energy resources, the exploitation of these resources could produce a enough electricity which could be provided to the northern hilly areas and the southern and western deserts. This will help in reducing dependency on fossil fuels import and also improve energy security.

Pakistan recorded a shortfall of 40 percent between demand and supply of electricity in 2008 [see Asif (2009)]. To overcome this shortfall, Pakistan has many sustainable energy option including hydro, biomass, solar, and wind resources. The total estimated hydropower potential is more than 42 GW and so for only 6.5 GW has been utilised. Although biomass is another conventional resource of energy in Pakistan but still it is commercialised. Solar and wind are also identified as potential energy resources but still it is not in operation on a vast scale.

This paper is analysing the effects of policies of restricting energy import and total primary energy supply on diversification of energy resources, technology mix in energy supply side and demand side; energy efficiency and energy conservation; and energy security during the planning horizon 2005–2050. A MARKAL-based model for an integrated energy system of Pakistan was developed to accomplish the research.

The paper is structured as follows. In Section 2 different policy options for energy security are presented. Section 3 gives an overview of Pakistan energy outlook. Section 4 provides the methodology and model formulation. Section 5 gives a brief description of the scenarios while analysis of the base case, energy import reduction case and primary energy supply reduction case is given in Section 6. Finally, Section 7 presents the main conclusions.

2. POLICY OPTIONS FOR ENERGY SECURITY IMPROVEMENT

Energy security is a wide and growing concept. In the 1970s and 1980s, energy security was perceived as reducing oil imports level and controlling the risks associated with those imports. Today, energy security takes into account other types of energy (i.e. natural gas and liquefied natural gas), and risks such as accidents, terrorism, under-investment in infrastructure and poorly designed markets. All of these might restrict sufficient supplies of energy at reasonable prices [see IEA (2007b)].

Now-a-days, the concept and definition of energy security is more broadened as compared to 1970s and 1980s concept. The broad definition of energy security contains four major elements i.e. physical availability of energy resources, accessibility to energy resources; affordability (economic element) and acceptability (environmental and societal element) [see IEA (2007c); APERC (2007); CIEP (2004)]. One can see clear conflict between affordability and acceptability as low energy cost will induce more energy demand and thus threats to environment and resource scarcity. On the other hand, achieving environmental targets will lead to higher energy cost.

From a poor developing country point of view, energy security is a very important component in their paths out of poverty [see Saghir (2006)]. Energy increases poor people's productivity and incomes; lighting and power improve their health and enable them to participate in education, and help them connect to the global market.

The International Energy Agency, World Bank and many other expect global energy demand to increase by at least 60 percent over the next 20 years. Two-thirds of the increase in global energy demand will come from developing countries. The dominant factors behind this global rising energy demand are sustained population rise in developing countries; urbanisation and expected improved mobility etc. [see Tempest (2004)].

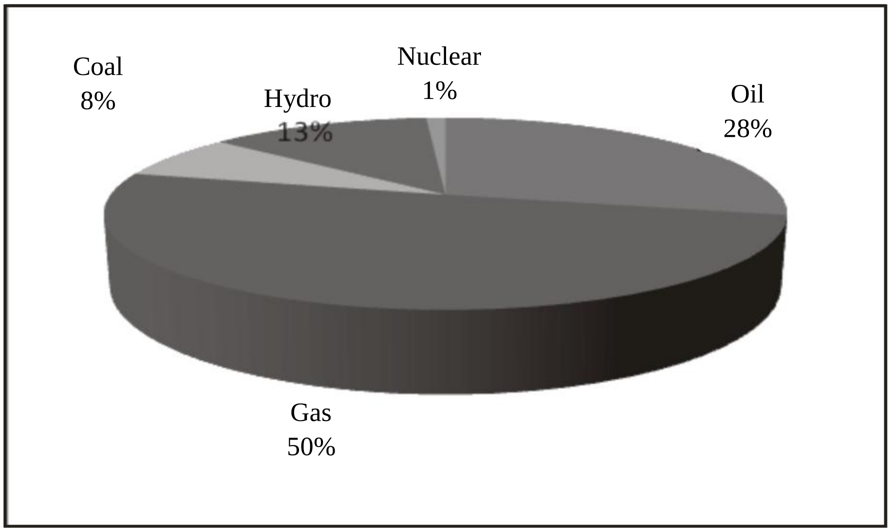
With the rapid increase in energy demand and energy prices, policy makers, researchers and stake holders in different institutions like International Energy Agency etc perceive that energy security would be the most important factor for the development of future energy policies of the different countries of the world. The main question in front of policy makers is: How to improve energy security and what are the different policy options? In the literature on energy security, a number of demand and supply side options to improve energy security of a country are discussed. The major options Total Primary Energy Supply Reduction, Energy Import Reduction, Renewable Energy Promotion, Carbon tax, Energy Conservation and Efficiency, Diversification of energy resources and sources of supply. These options may be different for developed, developing and less developed countries depending upon their energy needs, energy resources and the financial.

There are different types of energy security indices which are used to evaluate and distinguish different policy options in the energy security perspective [See Kruyt, *et al.* (2009); Grubb, *et al.* (2006); APEC (2006); Energy Research Centre of the Netherlands (2004)]. These indices are divided into simple indices or indicators, aggregated indices and some indicators are related to the various elements of energy security.

3. PAKISTAN ENERGY OUTLOOK

Pakistan energy sector consists of electricity, gas, petroleum and coal. Oil and gas are major contributors to the Pakistan primary energy supply mix. (Figure 1) The primary energy supply mix of Pakistan consists of 78 percent oil and gas, 13 percent hydro, 8 percent coal and 1 percent nuclear [see Pakistan (2006-07)]. Pakistan indigenous oil production meets only one-sixth of the current oil demand while imports one-third of the total energy demand. This implies that Pakistan's energy demand is more than the energy supply from the internal resources, and indicates that Pakistan is a net importer of energy.

Historical data shows that Pakistan has been dependent on oil imports from the Middle East since it came into being. The crude oil imports for the year 2005-06 was about 8.56 mtoe as compared to local production of crude oil 3.24mtoe and the imports of petroleum products were about 5.85 mtoe. The cost of all these oil and petroleum products was equivalent to US$ 4.6 billion which is roughly equal to 25-30 percent of the total import bill. This huge import bill put enormous pressure on the economy [Pakistan (2005)]. On the other side, the primary energy demand has increased significantly but the primary energy supply remained at same level, which created a huge gap between demand and supply. As a result, the country is facing huge energy shortage problems.

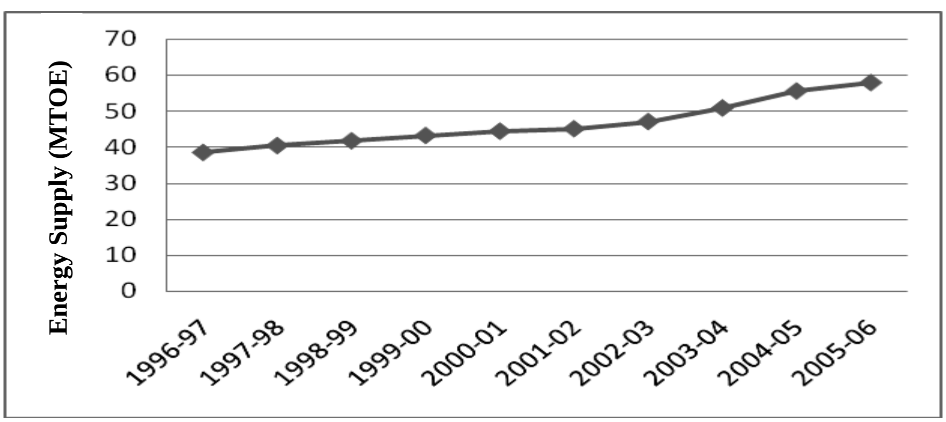


Source: Pakistan Economic Survey 2006-07.

Fig. 1. Primary Energy Supply by Source (2005-2006)

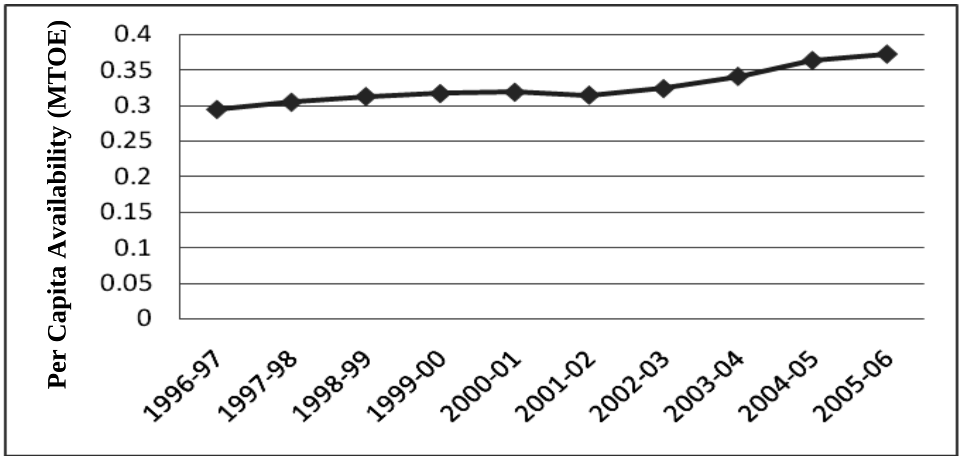
Pakistan imports about 29 percent of total primary commercial energy. Although Pakistan has a variety of energy resource, but approximately 80 percent of the energy supply is from oil and natural gas. The dependence on imported fuels especially on imported oil is likely to increase, which will affect badly Pakistan's economy. To avoid this negative impact, we should explore opportunities for untapped large renewable energy resources in the form of mini-hydro, solar and wind so that Pakistan can fulfil its energy needs and keep up its economic growth.

Figure 2 and Figure 3 display the annual trends of primary energy supplies and their per capita availability from 1996-97 to 2005-06, which indicates that the primary energy supply has increased by 50.2 percent and the per capita availability by 26 percent in the last 10 years.



Source: Pakistan Economic Survey 2006-07.

Fig. 2. Primary Energy Supply



Source: Pakistan Economic Survey 2006-07.

Fig. 3. Per Capita Energy Availability

4. METHODOLOGY

4.1. Model Formulation

This study makes use of bottom up MARKAL-based least cost energy system model as an analytical framework for the analysis of energy security in case of Pakistan [Loulou, *et al.* (2004)]. It models the flows of energy in an economy, from the source of primary energy supply, conversion of primary energy into secondary energy, and finally the delivery of various forms of energy to the end-use services. In the model, these flows of energy are described through detailed representation of technologies providing an end-use demand. Figure 4 shows the simplified structure of the MARKAL modelling framework through reference energy system of Pakistan.

Basically, Pakistan energy system model consists of four modules; primary energy supply, conversion technologies, end-use technologies and demand for energy services. Primary energy supplies are hydro, crude oil, natural gas, imports of oil, nuclear, solar wind etc, while conversion technologies module consists of power generation and transmission systems, oil refineries, natural gas processing and transmission systems. Service energy demand is grouped into five sectors: agriculture, residential, commercial, industrial and transport sector (see Figure 4).

End use demands are a measure of the useful energy output provided by the demand technologies in each end use demand category. It is assumed in MARKAL that the essential energy demand is for some service (an amount of cooking or heating), while the basic service is fixed, it can be provided by different mixes of devices and fuels. End-use demand technologies and conversion technologies are described in detail in Appendix A and B.

The objective function of the least cost energy system is to minimise the total discounted cost during the planning horizon; the total cost comprising of capital cost net of salvage value, fuel cost, operation and maintenance costs. The optimal solution given by the model must satisfy energy demand satisfaction, capacity and energy demand-supply balance constraints.

4.2. Service Demand Projection

Service energy demand is projected through three different techniques using econometric models as well as using identity relating service energy demand in particular sector to GDP and Value Added of the particular sector. In the econometric approach, we consider dependent variables such as number of energy devices, passenger kilometres, ton kilometres etc to be depended on independent variables such as Gross Domestic Product (GDP) and population, while the other approaches consider the service demand of particular sector in particular year is depended on the service demand of sector in base year multiplied by the ratio of the current year GDP and base year GDP; the service demand of particular sector in particular year is depended on the service demand of sector in base year multiplied by the ratio of the current year value added and base year value added.

The econometric approach was used to project the service energy demand in transport and residential sector, while the service energy demand in industrial, commercial and agriculture sector was projected through economic value added and GDP approach.

Service demand projection for fans, air conditioners and cooking is based on the GDP growth through the following formulation:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{GDP_t}{GDP_o}$$

Where $SD_{i,k,t}$, $SD_{i\ k,0}$ are service demand of sector i sub-sector k, in year t and base year respectively, GDP_t and GDP_0 represent Gross Domestic Product in year t and Gross Domestic Product in base year.

Service demand projection for agriculture, commercial and industrial sector is based on the following formulation:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{VA_{i,k,t}}{VA_{i,k,0}}$$

Where $SD_{i,k,t}$ is service demand of sector i subsector k in year t, $SD_{i\ k,0}$ is service demand of sector i subsector k in base year, $VA_{i\ k,0}$ is the ith sector kth subsector value added in the base year and $VA_{i\ k,t}$ is the ith sector kth subsector value added in the year t.

Electricity-related service demand and supply was considered in six time slices along with two seasons (summer and winter) and two periods (peak and off-peak) so that the variation of electricity loads on the energy system can be reflected.

5. SCENARIOS DESCRIPTION

Three scenarios were studied: (i) Base case, (ii) energy import reduction case, and (iii) primary energy supply reduction case. Details of the scenarios are expressed as follows.

5.1. Base Case

In this case, Pakistan GDP growth rate was assumed to grow at an annual growth rate of 7.0 percent and the growth rate of population was estimated at an annual growth rate of 1.9 percent based on the GDP and population data for the period of 2000-2013 [Pakistan (2006-07) and World Economic Outlook Database (2008)].

Under the base case, the maximum available stock of fossil energy resource (e.g., coal, oil and petroleum products, and natural gas) was estimated as the sum of proven reserve of the resource, its probable reserve and its possible reserve. In the power sector, renewable energy options (hydro, wind, and solar), natural gas-based power plants as well as nuclear power plant were included in the model. The options considered for the transportation sector include road, water and air transports.

5.2. Energy Import Reduction Case

For the classification of policy options for the improvement of energy security of Pakistan, we imposed three different types of energy import constraints in the MARKAL model for Pakistan. On the basis of these constraints, we analysed import dependency, diversification of energy sources and diversification of supplier of energy sources, vulnerability, and energy intensity for the whole planning horizon. The constraints are:

(a) **IEC05**—the target limit of energy import of alternative case is 95 percent of energy import of base case by 2050.
(b) **IEC10**—the target limit of energy import of alternative case is 90 percent of energy import of base case by 2050.
(c) **IEC15**—the target limit of energy import of alternative case is 85 percent of energy import of base case by 2050.

5.3. Primary Energy Supply Reduction Case

The policy of reducing primary energy demand is used to target energy efficiency in whole energy sector. In order to assess the performance of the policy both in terms of energy security and energy efficiency improvement, following alternative cases having different targets of total primary energy demand are analysed. Apart from the special constraint defined bellow for each case all other things are kept same as in the base case. The constraints are:

(a) **TPEC95**—Target is limiting total primary energy demand of alternative case to 95 percent of total primary energy demand of base case by 2050.
(b) **TPEC90**—Target is limiting total primary energy demand of alternative case to 90 percent of total primary energy demand of base case by 2050.

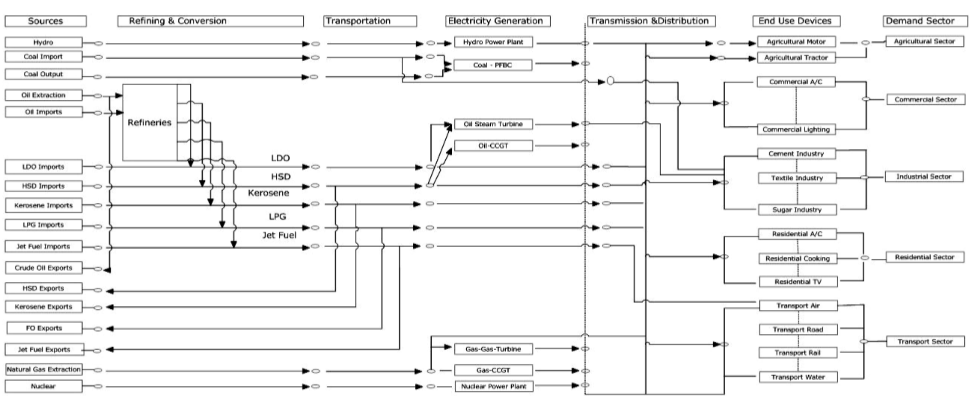


Fig. 4. Reference Energy System for Pakistan

6. ANALYSIS OF THE BASE CASE

Energy system development of Pakistan during the planning horizon of 2000-2035 under the base case is discussed as follows:

6.1. Primary Energy Supply in the Base Case

As can be seen from Figure 5, the primary energy supply in the base case shows an increasing trend over the whole planning horizon 2005-2050 indicating the rising energy supply and per capita energy availability. The primary energy supply in Pakistan is found to increase from 2894.4 PJ in base year to 26204.6 PJ by 2050. Results from model simulation show that Oil is the major part of primary energy supply through out the planning horizon, while gas, coal, renewable and nuclear are also contributing to primary energy supply.

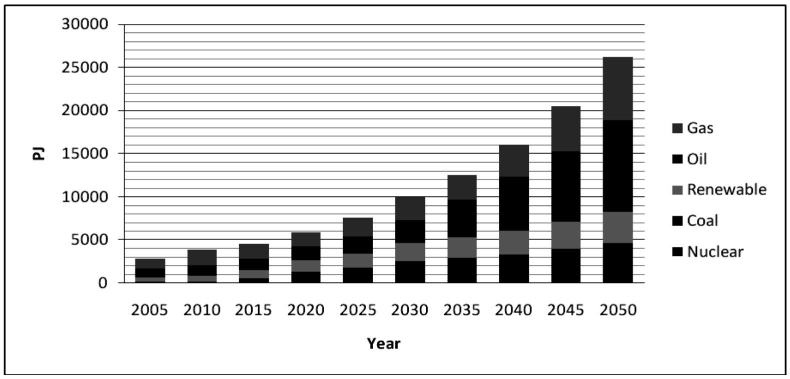


Fig. 5. Primary Energy Supply in Base Case

The fuel consumption in the base case is shown in Fig 6 consisting of coal, diesel, gasoline, fuel oil, jet oil, kerosene, LPG and others. During the planning horizon, the fuel consumption mix of Results from estimated model show that gas and oil products gas would have the largest share in total fuel consumption by 2050 followed by coal, LPG and other fuels. Although, gas hold the largest share in fuel consumption in the base year, the percentage share of gas in fuel consumption is declined from 46 percent in 2005 to 28 percent by 2050, while the percentage shares of oil in fuel consumption is increased from 37 percent in 2005 to 41 percent by 2050.

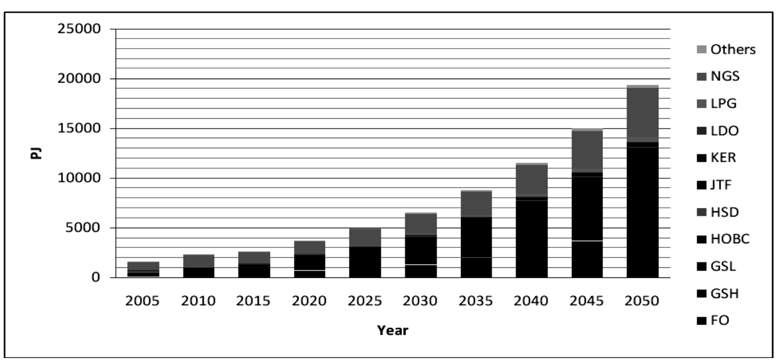


Fig. 6. Fuel Consumption in Base Case

As can be seen from Figure 7, sector wise fuel consumption in the base year is dominated by industrial followed by transport, residential, commercial and agriculture sector and same trend is prevailed for the whole planning horizon 2005–2050.

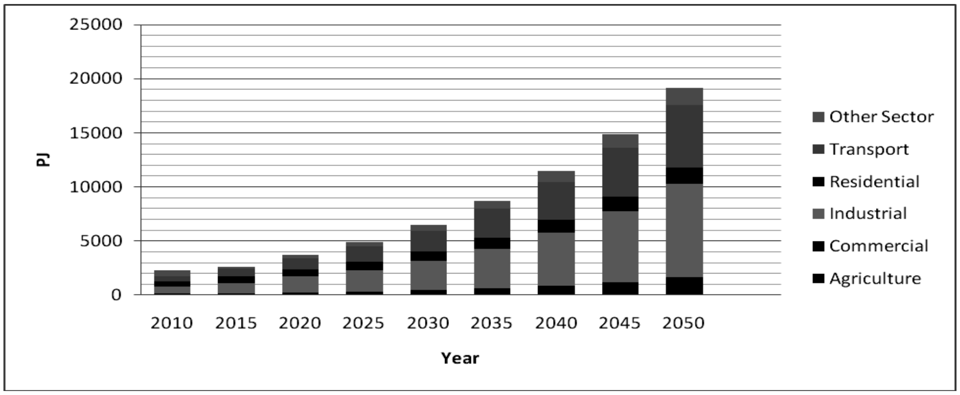


Fig 7. Sector wise Fuel Consumption in Base Case

6.2. Energy Security Indices in Base Case

The prime objective of this research is to classify policy options for the improvement of energy security of Pakistan. The fundamental and suitable criterion for the classification of policy options are the calculation of energy security indices for the whole planning horizon 2000-2035. In this study, four energy security indicators are used, i.e., Net Energy Import Ratio (NEIR), Shannon-Wiener Index (SWI), Diversification of Primary Energy Demand (DoPED) and Vulnerability Index (VI) are estimated by using the MARKAL model which is energy-system model depicting long-term development of the energy-system. Those indicators are explained as follows:

$$NEIR = \frac{Net\ Importers}{(Domestic\ Production + Net\ Importers)}$$

The value of NEIR close to 1 indicates that the energy system of that country is to a large extent dependent on energy imports.

$$SWI = -\sum_i x_i \ln(x_i)$$

where x_i represents the share of energy supply from each source. A higher value of SWI means well diversified energy sources ultimately leading to improved energy security while a lower value implies low diversification of energy sources and poorer energy security [Grubb, *et al.* (2006)].

$$DoPED = \frac{\sqrt{Coal^2 + Oil^2 + Hydro^2 + Biomass^2 + Other^2}}{Total\ Primary\ Energy\ Demand}$$

Where the value of *DoPED* close to 1 indicates that the economy is reliant on one energy resource while a value close to zero (0) means that the energy sources in the economy are uniformly spread among several energy resources.

6.3. Energy Security under Energy Import Reduction

For the classification of policy options for the improvement of energy security of Pakistan, we imposed three different types of constraints (e.g. IEC5, IEC15, IEC20). These constraints are briefly explained in section 5.2) in the MARKAL model for Pakistan. On the basis of these constraints, we analysed import dependency, diversification of energy resources, vulnerability, and energy intensity for the whole planning horizon.

As can be seen from Figure 8, primary energy supply under 5 percent and 10 percent energy import reduction decreases as compared to the base year case, while primary energy supply under 15 percent energy import reduction increased as compared to the base case.

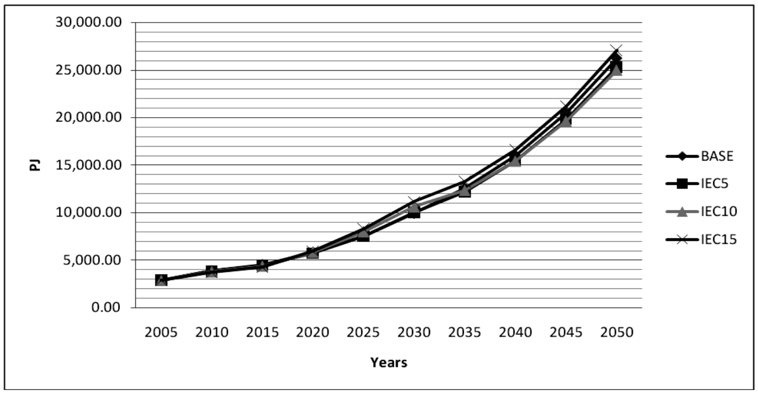


Fig.8 Primary Energy Supply under Energy Import Reduction

6.3.1. *Energy Import Dependency under Energy Import Reduction*

Net Energy Import Ratio (NEIR) is an important index used for the analysis of energy security and it is also used an approximate measure for energy import dependency. As can be seen from Figure 9, the net energy imports from the rest of the world indicated by NEIR would reduce. The reason for this declining import dependency would be the increased shares of indigenous energy resources (coal and renewable) in the energy system. Ultimately, the energy security of Pakistan would be obviously improved during 2005–2050.

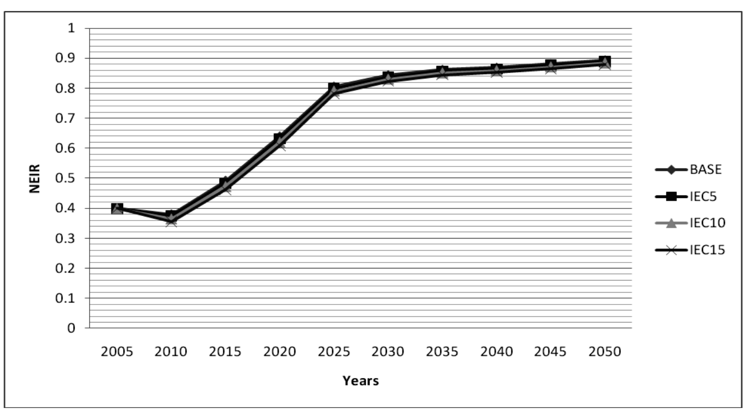


Fig. 9. Import Dependency

6.3.2. *Diversification under Energy Import Reduction*

Diversification of energy resources plays a crucial role in the improvement of energy security. *DoPED* and SWI are used to show the variation of diversification among different energy resources. As can be seen from Fig. 10, the value of *DoPED* reduced from 0.61 in the 2005 to 0.52 by 2050 under 15 percent energy import reduction implying better diversification among different energy resources as compared to the base case. Diversification can also be analysed through Shannon-Wiener Index (SWI); higher value of SWI implies better diversification among different energy resources. Figure 11 depicted the model simulated values for SWI which indicates that the value of SWI increases from 0.49 in 2000 to 0.58 in 2050 under the energy import restrictions showing better diversification among energy resources in all cases of the planning horizon (2000–2050). Both the indices ultimately would imply better diversification of energy resources by 2050 as compared to 2005 that lead to energy security improvement in Pakistan by 2035.

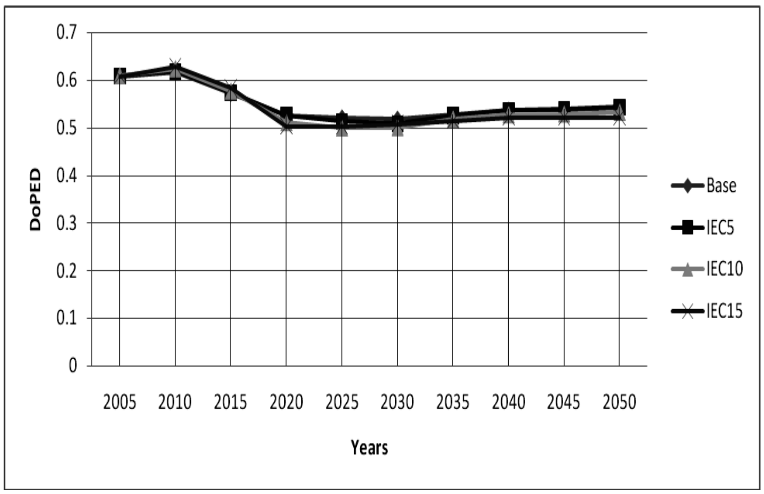


Fig. 10. Diversification of Energy Resources (DoPED)

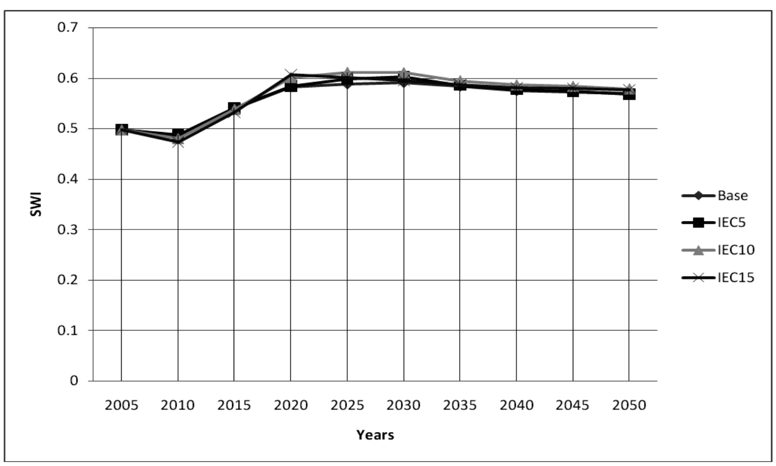


Fig. 11. Diversification of Energy Resources (SWI)

6.4. Energy Security and Primary Energy Supply Reduction

Primary energy supply reduction is another direct policy option to improve energy security of the country. This policy works through increased energy efficiency and fuel switching that reduce primary energy demand. Efficient technologies will be selected when reduced primary energy supply and final energy demand will be decreased due to high efficiency of efficient technologies that will lead to primary energy demand reduction.

6.4.1. *Primary Energy Supply under Primary Energy Supply Reduction Constraint*

As can be seen from Figure 12, total primary energy supply in the base case is more then other cases where model restrict the primary energy supply by 95 percent and 90 percent of the base case. The reduction in primary energy supply is smooth in all the primary energy reduction constraints during the whole planning horizon 2005–2050. Total primary energy reduction targets do not help to improve the energy security of the country but they help to improve the overall efficiency in the energy system.

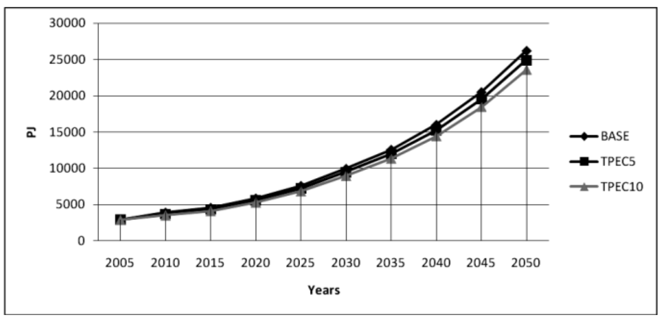


Fig. 12 Primary Energy Supply under Primary Energy Supply Reduction

6.4.2. *Energy Import Dependency under Primary Energy Supply Reduction Constraint*

The energy import dependency represented by net energy import ratio (NEIR) shown in Figure 13 is reflecting lower amount of energy import by 2005 as compared to base case. This decrease in net energy import ratio implies improved energy security. Therefore, primary energy supply reduction may be an appropriate policy option for reducing import dependency and the enhancement of energy security.

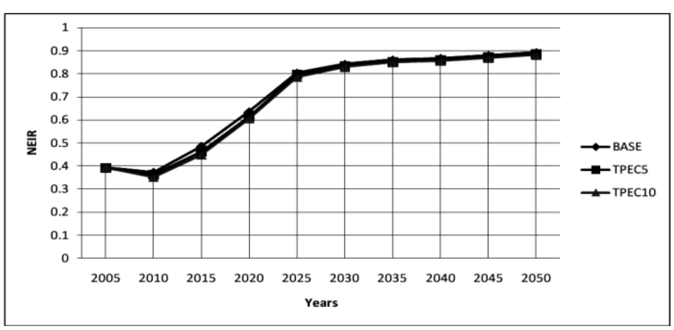


Fig. 13. Net Energy Import Ratio under Primary Energy Supply Reduction

6.4.3. *Diversification under Primary Energy Supply Reduction Constraint*

Beside the import dependency factor, diversification is another important factor of the energy security for developing and developed countries. Diversification can be viewed from two perspectives: diversification of energy sources and diversification of supplier of energy sources. As can be seen from Figure 14, the value of DoPED decreases from 0.60 in 2000 to 0.55 in 2050 i.e., diversification of primary energy resources improved by 9 percent by 2035 as compared to 2000. The same result is obtained through SWI shown in Figure 15. The value of SWI increases from 0.49 in 2000 to 0.558 indicating better diversification of energy resources by 2050 as compared to the base case. The improved diversification of energy resources by 2050 leads to enhanced energy security.

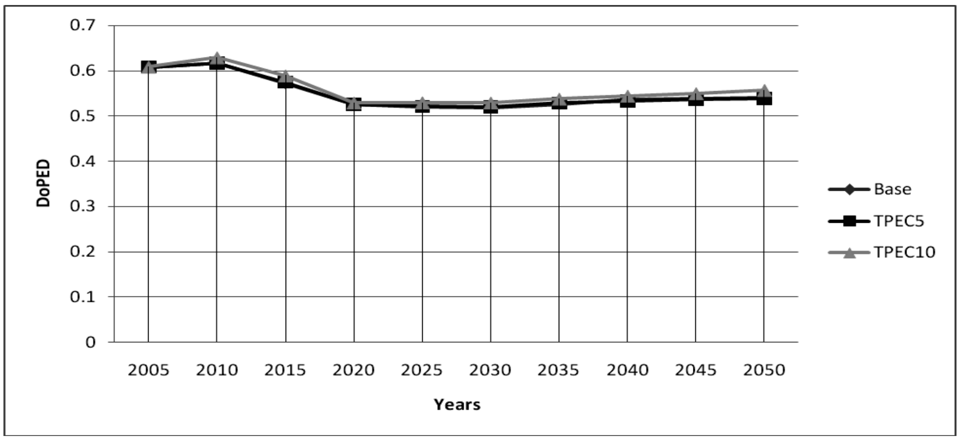


Fig. 14. DoPED under Primary Energy Supply Reduction

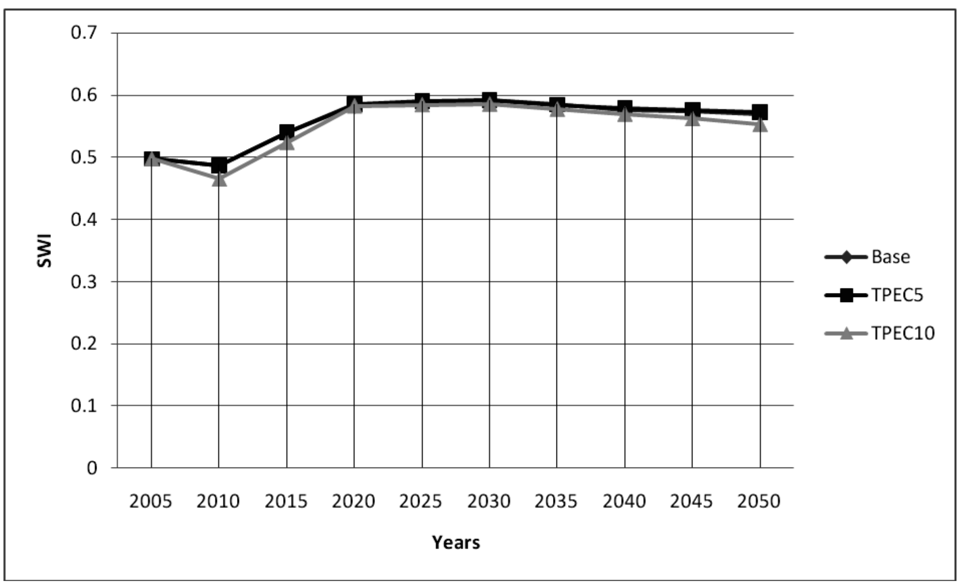


Fig. 15. SWI under Primary Energy Supply Reduction

7. CONCLUSIONS

This paper investigates the effects of policies of restricting energy import and total primary energy supply on diversification of energy resources, technology mix in energy supply side and demand side; energy efficiency and energy conservation; and energy security during the planning horizon 2005-2050. A MARKAL-based model for an integrated energy system of Pakistan was developed for this cause.

The study also provided a very brief overview of different policy options for the enhancement of energy security. Restricting energy import and primary energy supply are the two policy options which are implemented in the MARKAL model for Pakistan for the analysis of energy security. The effects of these two policies on the energy security of Pakistan are analysed through the estimation of energy security indicators for the base case as well as for these two policy options with the planning horizon 2005–2050.

Restricting energy import is a direct and command type of policy option for the improvement of energy security and is appearing to be working in case of Pakistan. Looking at the energy security indicators, all energy security indicators in case of energy import reduction demonstrate improvement in the energy security as compared to base case. Net energy import ratio decreases, diversification of energy resources improves. Therefore, energy import reduction may be one of the best policy options for the improvement of energy security of Pakistan.

Primary energy supply reduction is another direct policy option to improve energy security that works through increased energy efficiency and fuel switching that ultimately reduces primary energy demand. By restricting primary energy supply, energy import dependency decreased in all cases as compared to base case. Diversification of energy resources demonstrates quite considerable improvement as compared to base case. All these facts imply that primary energy supply reduction can be used one of the policy options for the enhancement of energy security in case of Pakistan.

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