

The Role of Renewable Energy Supply and Carbon Tax in the Improvement of Energy Security:
A Case Study of Pakistan

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Abstracts

In this paper, we examine the effects of renewable portfolio supply (RPS), and carbon tax on diversification of energy resources, technology mix in energy supply side and demand side, energy efficiency, energy conservation and energy security during the planning horizon 2005-2050. The analyses are based on a long term integrated energy system model of Pakistan using the MARKAL framework to analyze the long term effects of different policy options during 2005-2050. The effects related to energy security are represented through a set of energy security indicators such as energy import dependency, diversification of energy resources through DoPED and SWI, and vulnerability. Renewable Portfolio Standards (RPS) is a policy option to improve energy security. As renewable energy sources are a very small portion of Pakistan primary energy mix, therefore RPS may not be a suitable policy option for energy security improvement in the short run, but may help in the improvement of energy security in the long term. Carbon tax is an indirect policy option for energy security enhancement working through emission reduction. As carbon tax is not a direct policy option for enhancement of energy security and it targets emission reduction, but still it affect the energy import and the shares of other primary energy sources. Therefore, policy of renewable portfolio supply and carbon tax may be policy options for the enhancement of energy security.

Key Words: Renewable portfolio supply (RPS), Carbon tax, Energy supply and technology implications, MARKAL based Pakistan energy system model,

1. Introduction

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.

Renewable portfolio supply (RPS), and carbon tax are the two indirect policy options used for the improvement of energy security. Renewable Energy Promotion is used to reduce green house gas emission, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. Carbon tax is an indirect policy option for energy security enhancement working through emission reduction. Imposing tax on carbon emission will alter the primary energy supply mix, more efficient fuel and technologies will be switched with less efficient fuel and technologies. This will reduce the primary energy demand and lead to improve energy security.

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 analyzed 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 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% between demand and supply of electricity in 2008 (see Asif, M., 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 far only 6.5 GW has been utilized. Although biomass is another conventional resource of energy in Pakistan but still it is not commercialized. Solar and wind are also identified as potential energy resources but still it is not in operation on a vast scale.

This paper is analyzing the effects of policies of renewable portfolio supply (RPS), and carbon tax 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 gives an overview of Pakistan energy outlook. Section 3 provides the methodology and model formulation. Section 4 gives a brief description of the scenarios while analysis of the base case, renewable portfolio supply case and carbon tax case is given in Section 5. Finally, Section 6 presents the main conclusions.

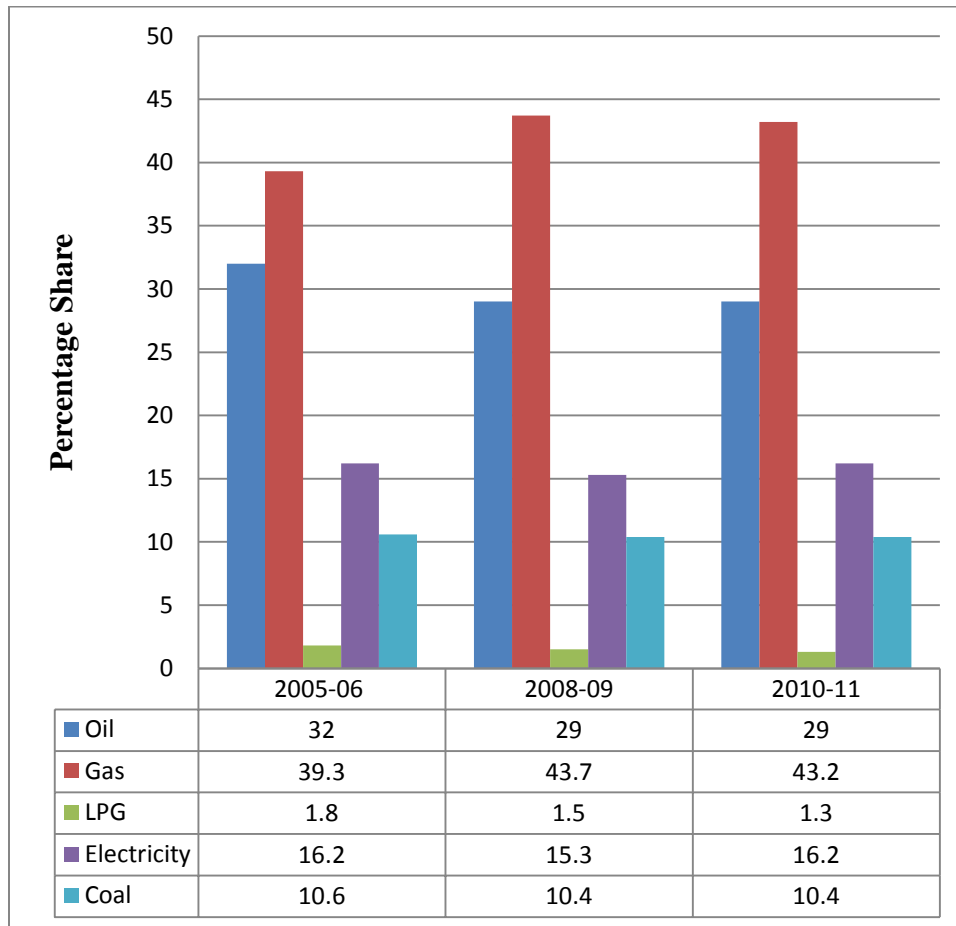
2. Pakistan Energy Outlook

Pakistan energy sector consists of electricity, gas, petroleum and coal. Oil and gas are major contributors to the Pakistan primary energy supply mix. (Fig. 1.) The primary energy supply mix of Pakistan consists of 78% oil and gas, 13% hydro, 8% coal and 1% nuclear (see Pakistan Economic Survey, 2006-07). The most interesting feature of Pakistan primary energy supply mix is that share of oil decreases from 32% in 2005-2006 to 29% in 2010-2011, and share of gas increases from 39% in 2005-2006 to 43% in 2010-2011, while the shares of other resources are

remained almost constant over the same period. It shows that Pakistan energy sector is switching from oil to gas and other resources.

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.

Fig. 1. Primary Energy Supply Mix (2005-2010)



Source: Pakistan Economic Survey 2011-12

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 3.24 mtoe 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 Energy Yearbook, 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.

Pakistan imports about 29% of total primary commercial energy. Although Pakistan has a variety of energy resource, but approximately 80 % 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 fulfill its energy needs and keep up its economic growth.

Table-1 displays 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% and the per capita availability by 26% in the last 10 years.

Table-1. Primary Energy Supply and Per Capita Availability

Year	Primary Energy Supply (Tons of Oil Equivalent)	% Change	Per Capita Availability (Tons of Oil Equivalent)	% Change
1996-97	38.515	-0.6	0.295	-3.0
1997-98	40.403	4.9	0.305	3.3
1998-99	41.721	3.3	0.313	2.7
1999-00	43.185	3.5	0.317	1.2
2000-01	44.404	2.8	0.319	0.6
2001-02	45.068	1.5	0.315	-0.1
2002-03	47.056	4.4	0.324	2.7
2003-04	50.831	8.0	0.341	5.3
2004-05	55.533	9.3	0.363	6.7
2005-06	57.855	4.2	0.372	2.2

Source: Pakistan Economic Survey 2006-07

3. Methodology

3.1 Model Formulation

This study makes use of bottom up MARKAL-based least cost energy system model¹ 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. Fig. 2 shows the simplified structure of the MARKAL modeling framework through reference energy system.

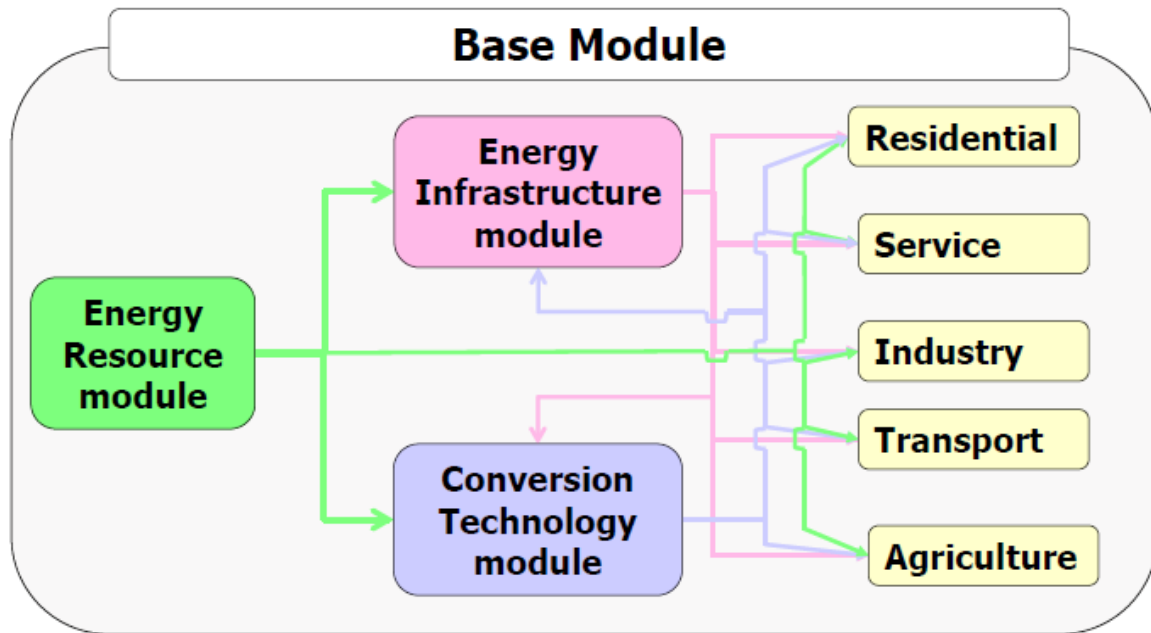
Basically, Pakistan energy system model consists of four modules; primary energy supply, conversion technologies, end-use technologies and demand for energy services. Primary energy supplies are hydro, crude oil, natural gas, imports of oil, nuclear, solar wind etc, while conversion technologies module 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 Fig. 2.).

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&B.

The objective function of the least cost energy system is to minimize 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.

¹ Model formulation is described in Appendix-C.

Fig.2 General Reference Energy System



Source: www.ukerc.ac.uk/support/tiki-download_file.php?fileId=951

3.2 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 kilometers, ton kilometers 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:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{GDP_t}{GDP_0}$$

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 i_{th} sector k_{th} subsector value added in the base year and $VA_{i,k,t}$ is the i_{th} sector k_{th} 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.

4. Scenarios Description

Three scenarios were studied: (i) Base case, (ii) renewable portfolio supply (RPS) case, and (iii) carbon tax case. Details of the scenarios are expressed as follows.

4.1 Base Case

In this case, Pakistan GDP growth rate was assumed to grow at an annual growth rate of 7.0% and the growth rate of population was estimated at an annual growth rate of 1.9% based on the GDP and population data for the period of 2000-2013 (Pakistan Economic Survey 2006-07, 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 (see Appendix B). The options considered for the transportation sector include road, water and air transports.

4.2 Renewable Portfolio Supply Scenario

Renewable Energy Promotion is used to reduce emission, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. To assess the effects of renewable portfolio supply (RPS), we implemented five different constraints and calculated energy security indicators for the whole planning horizon 2005-2050. The constraints are:

- a. **RPS10**- Total of renewable based electricity generation is set to be 10% of total electricity generation (excluding large hydro) during period of 2005 to 2050.
- b. **RPS20**- Total of renewable based electricity generation is set to be 20% of total electricity generation (excluding large hydro) during period of 2005 to 2050.
- c. **RPS30**- Total of renewable based electricity generation is set to be 30% of total electricity generation (excluding large hydro) during period of 2005 to 2050.
- d. **RPS40**- Total of renewable based electricity generation is set to be 40% of total electricity generation (excluding large hydro) during period of 2005 to 2050.
- e. **RPS50**- Total of renewable based electricity generation is set to be 50% of total electricity generation (excluding large hydro) during period of 2005 to 2050.

4.3 Carbon Tax Scenario

Carbon tax is an indirect policy option for energy security enhancement working through emission reduction. Imposing tax on carbon emission will alter the primary energy supply mix, more efficient fuel and technologies will be switched with less efficient fuel and technologies. This will reduce the primary energy demand and lead to improve energy security. To assess the

effects of carbon tax on energy security, we implemented different constraints in the model. The constraints are:

- a. **CO₂-10**- Impose a tax of 10US\$/tCO₂ until 2050.
- b. **CO₂-15**- Impose a tax of 15US\$/tCO₂ until 2050.
- c. **CO₂-20**- Impose a tax of 20US\$/tCO₂ until 2050.
- d. **CO₂-25**- Impose a tax of 25US\$/tCO₂ until 2050.
- e. **CO₂-30**- Impose a tax of 30US\$/tCO₂ until 2050.

5. Analysis of the Base Case

Energy system development of Pakistan during the planning horizon of 2005-2050 under the base case is discussed as follows:

5.1 Primary Energy Supply in the Base Case

As can be seen from Fig. 3, the primary energy supply in the base case under the renewable portfolio supply scenario 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 2475 PJ in 2005 to 35,559 PJ in 2050. Results from model simulation show that oil and gas are the major parts of primary energy supply in the base case, while coal and renewable are also contributing to primary energy supply. Over the time, primary energy supply mix is changed and the cheap resources (renewable and coal) dominated the primary energy supply mix.

As can be seen from Fig. 4, the primary energy supply in the base case under the carbon tax scenario shows an increasing trend over the whole planning horizon 2005-2050. The primary energy supply is estimated to increase from 2475 PJ in 2005 to 22,684 PJ in 2050. Results from model simulation show that oil and gas have major contribution of primary energy supply in the base case, while coal and renewable are also contributing to primary energy supply. Over the time, primary energy supply mix is changed and the cheap resources (renewable) and oil dominated the primary energy supply mix while.

Sector wise fuel consumption in both scenarios is presented in Fig-5 and Fig-6. In the renewable portfolio supply scenario, industrial sector, residential sector and transport sector dominate the sectoral fuel consumption in 2005, while the shares of industrial sector and transport sector has increased considerably while share of residential sector has declined in 2050. Similarly under carbon tax scenario, transport sector holds the largest share in the sector wise fuel consumption followed by industrial sector and residential sector in 2005, while the share of residential sector has declined and shares of transport sector and industrial sector has grown significantly in 2050.

Fig. 3
Primary Energy Supply in Renewable Portfolio
Supply Scenario in base case
(PJ)

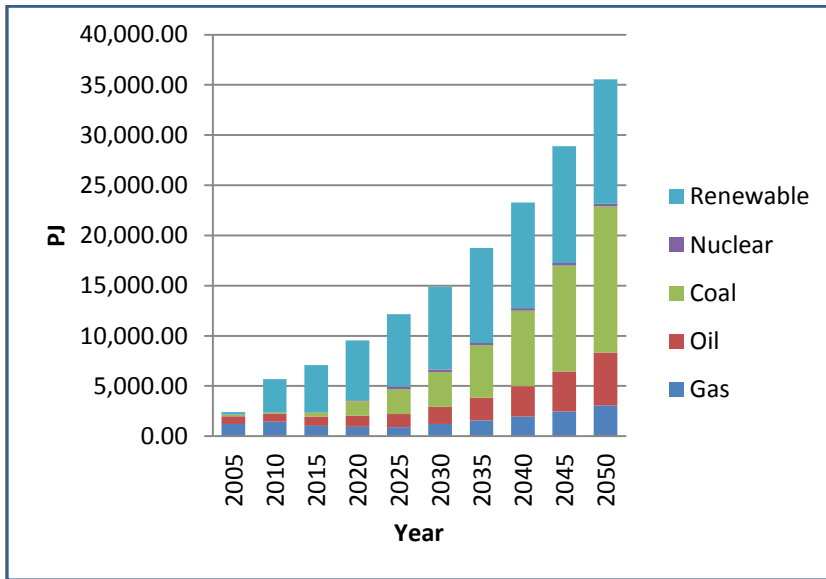


Fig. 4
Primary Energy Supply in Carbon Tax Scenario
in base case
(PJ)

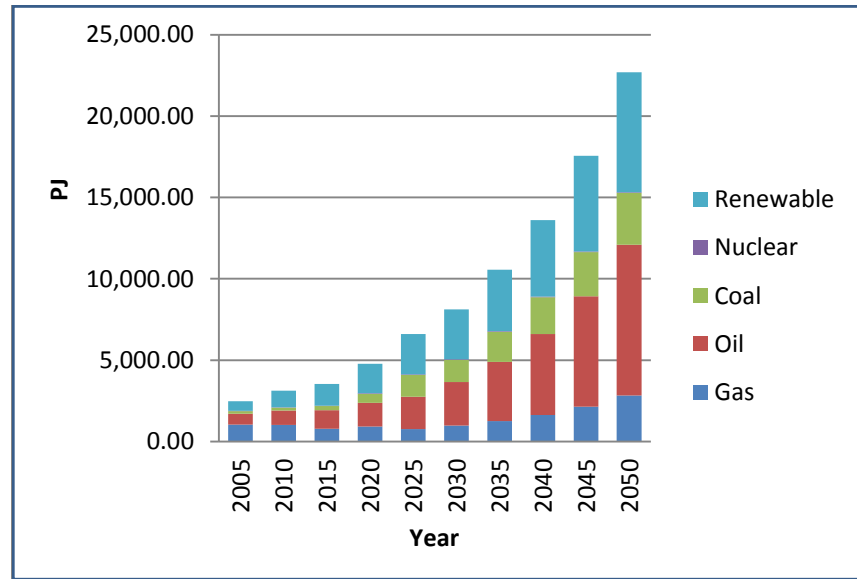


Fig 5.
Sectoral Energy Consumption in Renewable Portfolio Supply Scenario
(Percentage Share)

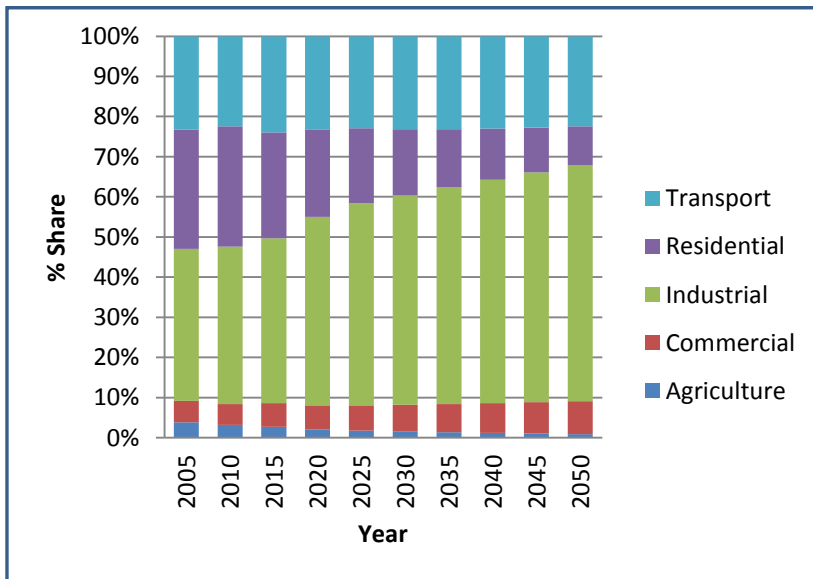
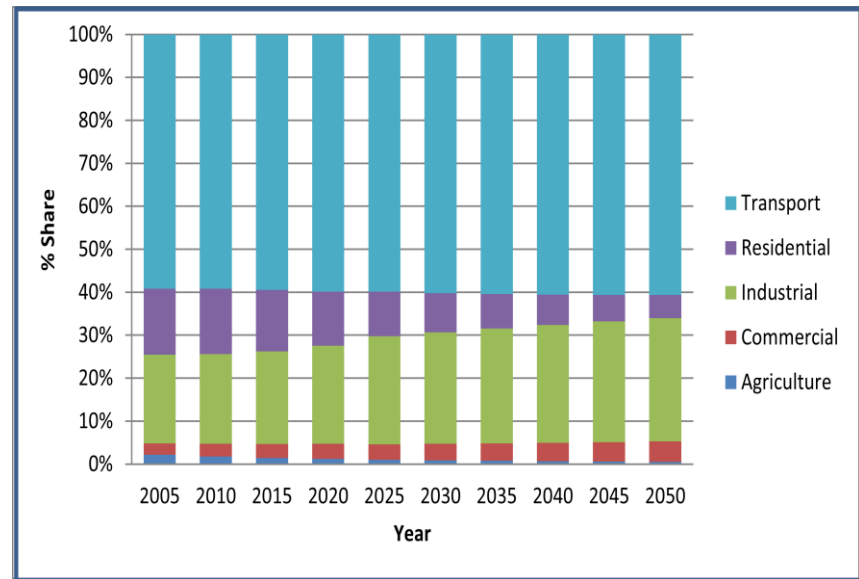


Fig 6.
Sectoral Energy Consumption in Carbon Tax Scenario
(Percentage Share)



5.2 Energy Security Indices

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 2005-2050. 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), Vulnerability Index (VI) and Energy Intensity (EI) 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:

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

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.

Vulnerability may be linked to strong energy import dependency i.e. it may also be linked to the high level of energy import value in GDP. It refers both to the quantity and cost of energy imports.

$$VI = \frac{EEI}{GDP}$$

where; EEI is expenditure on energy import and GDP is Gross Domestic Product.

$$EI = \frac{TPES}{GDP}$$

Where EI is Energy Intensity, TPES is Total Primary Energy Supply and GDP is Gross Domestic Product.

5.4 Energy Security under Renewable Portfolio Supply and Carbon Tax Scenario

For the classification of policy options for the improvement of energy security of Pakistan, we imposed five different types of Renewable Portfolio Supply and Carbon Tax constraints (These constraints are briefly explained in section-4.2 and 4.3) in the MARKAL model for Pakistan. On the basis of these constraints, we analyzed import dependency, diversification of energy resources, vulnerability, and energy intensity for the whole planning horizon.

5.4.1 Energy Import Dependency under Renewable Portfolio Supply and Carbon Tax Scenario

Energy Import Dependency is one of the key aspects of energy security that can be calculated as a percentage of net energy imports in total primary energy supply. Energy security indicator based on net energy import ratio (NEIR) is shown in Fig-7 and Fig-8. As can be seen from Fig-7, the net energy imports from the rest of the world indicated by NEIR would increase from 24% in 2005 to 41% in 2050 under renewable portfolio supply scenario indicating higher energy import dependency, but as more renewable energy resources are exploited and entered in the energy system, the energy import dependency has decreased from 41% in base case to 38% in RPS50 scenario which is a considerable reduction in energy import dependency. The main factor behind the reduction of energy import dependency is the share of renewable resources based electricity generation in the total electricity generation which is increased significantly as compared to the base case and that is a signal towards energy security improvement in Pakistan.

On the other side, energy import dependency under carbon tax scenario would increase from 24% in 2005 to 45% in 2050 as shown in Fig-8. Energy import dependency in carbon tax scenario has a mixed trend, but as more and more carbon tax is imposed, import dependency has

increased. The main reason behind the increased energy import dependency is increased share of imported oil in the primary energy supply in 2050 under carbon tax scenario.

Fig 7

Import Dependency under Renewable Portfolio Supply Scenario

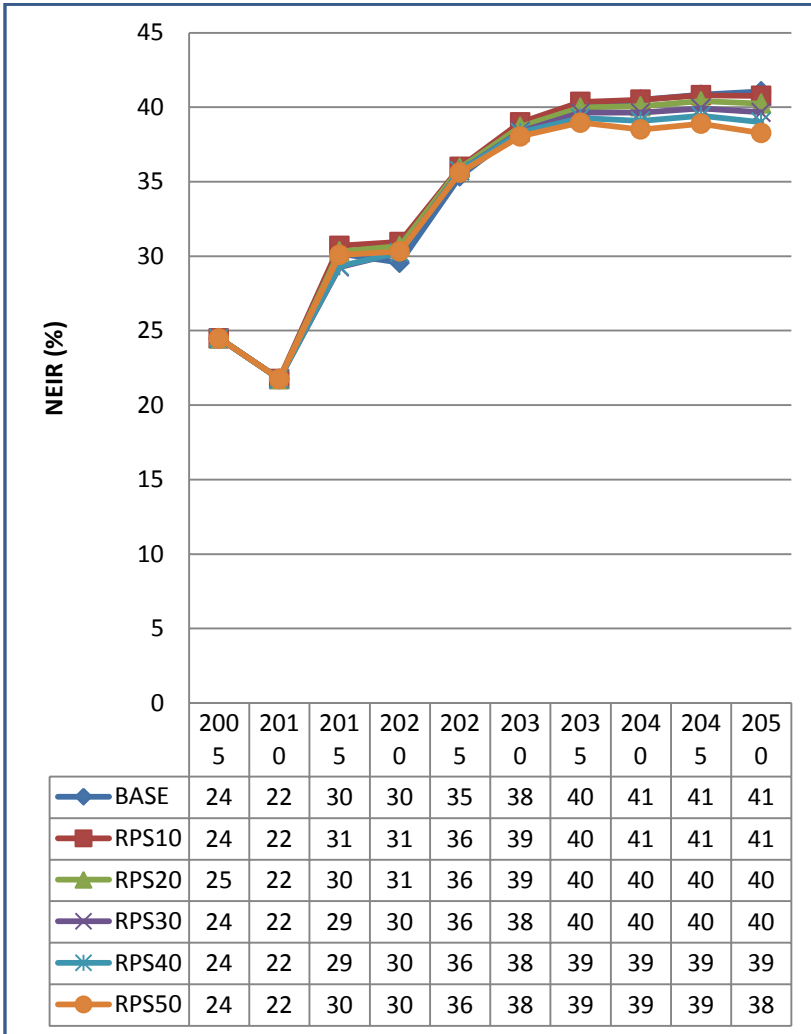
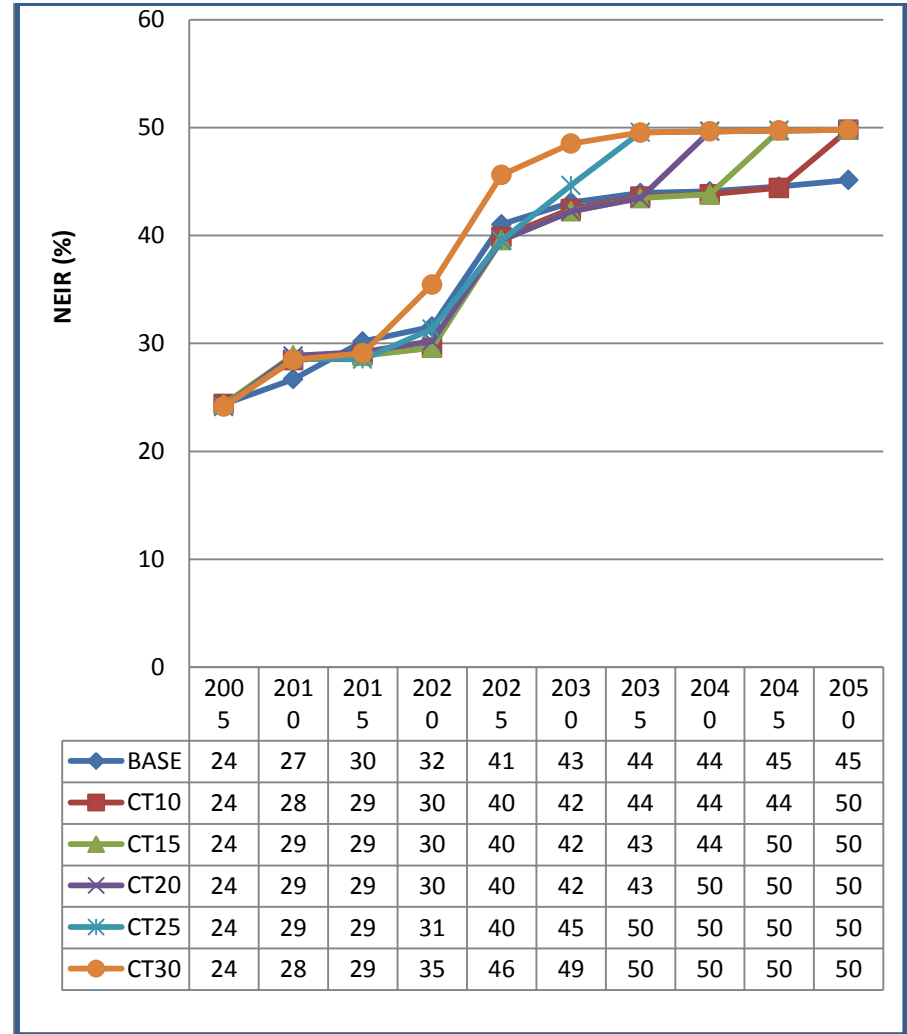


Fig 8

Import Dependency under Carbon Tax Scenario



5.4.2 Diversification under Renewable Portfolio Supply and Carbon Tax Scenario

Diversification of primary energy sources is another important factor of energy security. DoPED and Shannon-Wiener Index (SWI) illustrate the diversification of the primary energy supply mix of the future energy system. As can be seen from Fig -9, the value of DoPED reduced from 61% in the 2005 to 56% in 2050 in the base case implying better diversification among different energy resources under the renewable portfolio supply scenario. Diversification has worsen up to 2015 and then in the long run, it has shown better situation up to 2050 in all renewable portfolio supply scenarios. On the other hand, diversification under carbon tax scenario reflected somewhat mixed phenomenon (Fig-10). First, diversification of energy resources improved up to 2025 in the base case and then it has declined up to 2050. While in case of all carbon tax scenarios, diversification has shown better position up to 2035 and then started to become worsen up to 2050.

Diversification can also be examined through Shannon-Wiener Index (SWI); higher value of SWI implies better diversification among different energy resources. Fig-11 and Fig-12 depicted the model simulated values for SWI under the renewable portfolio supply and carbon tax scenario. As can be seen from Fig -11, the value of SWI increased from 51% in the 2005 to 55% in 2050 in the base case implying better diversification among different energy resources under the renewable portfolio supply scenario. Diversification has worsen up to 2015 and then in the long run, it has shown better situation up to 2050 in all renewable portfolio supply scenarios. On the other side, diversification under carbon tax scenario demonstrated a mix of better and worse diversification in different time periods (Fig-12). First, diversification of energy resources improved up to 2025 in the base case and then it has declined up to 2050. While in case of all carbon tax scenarios, diversification has shown better position up to 2035 and then started to become worsen up to 2050.

Both the indices ultimately would imply better diversification of energy resources by 2035 as compared to 2005 that lead to energy security improvement in Pakistan by 2035.

Fig 9

Diversification of Energy Resources under Renewable Portfolio Supply Scenario

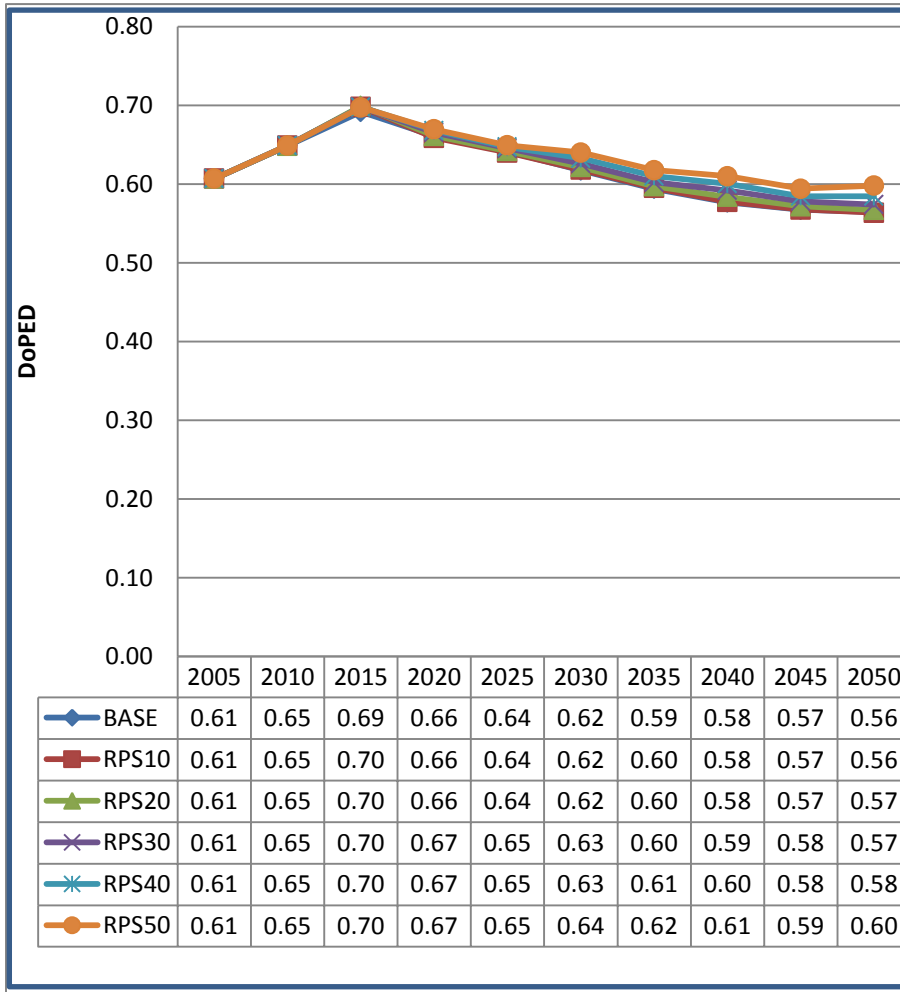


Fig 10

Diversification of Energy Resources under Carbon Tax Scenario

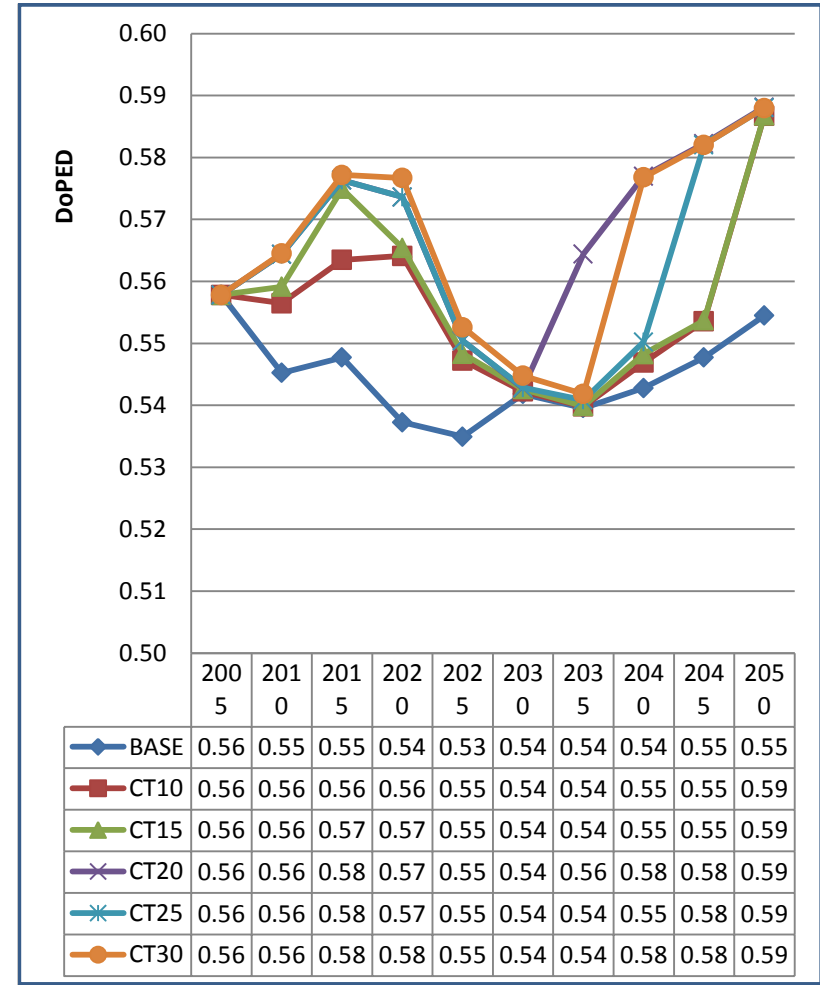


Fig 11

Diversification of Energy Resources under Renewable Portfolio Supply Scenario

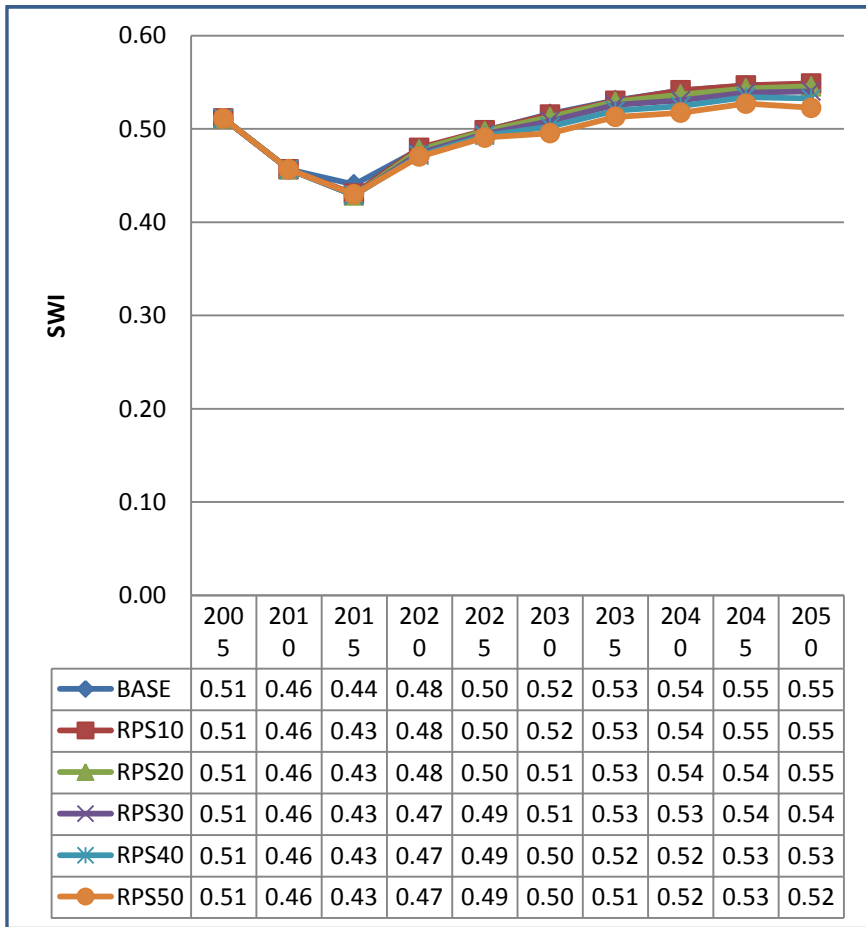
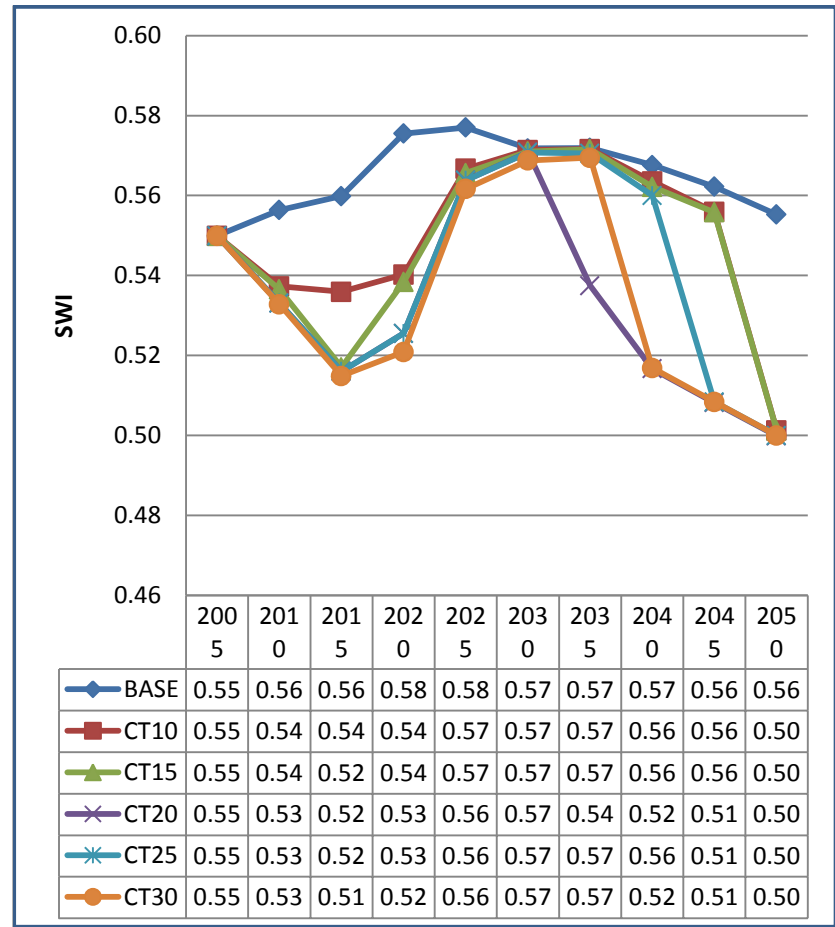


Fig 12

Diversification of Energy Resources under Carbon Tax Scenario



5.4.3 Vulnerability and Energy Intensity under Renewable Portfolio Supply and Carbon Tax Scenario

The energy security indices NEIR, SWI, and DoPED quantify the physical availability of primary energy supply to the energy sector of the economy ignoring the monetary significance of energy imports. To capture the economic significance of energy imports, we used vulnerability index.

As can be seen from Fig-13, vulnerability under renewable portfolio supply scenario shows a declining trend up to 2020 and then reflecting rising trend up to 2050 in the base case as the amount of imports in the total primary energy increased over the time. Under all renewable supply portfolio scenarios, vulnerability exhibits the trend, but, however, it declined with more and more renewable energy is entering in the system over the time. The declining behavior of vulnerability index (Fig 13) implies that vulnerability will decrease in the long run as compared to short run in all cases that will lead to enhanced energy security of Pakistan under the renewable portfolio supply scenarios.

Under carbon tax scenario, vulnerability is reduced up to 2020 in base case as well as in all carbon tax scenarios and it increased up to 2050 (Fig-14). The main reason of increasing vulnerability is the rising shares of energy imports from the Middle East which has caused Pakistan Economy badly.

The other energy security indicator such as energy intensity (Fig-15 and Fig-16) is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP. High energy intensities indicate a high price or cost of converting energy into GDP and low energy intensity indicates a lower price or cost of converting energy into GDP. In case of renewable portfolio supply scenario, energy intensity has a rising trend showing economic inefficiency in the base case (Fig-15), while energy intensity has decreased with the inclusion of renewable energy in the system that reflected an economic efficiency of the energy system under all renewable portfolio supply scenarios. This is an indication of energy security enhancement in the renewable portfolio supply scenarios.

In case of carbon tax scenario (Fig-16), energy intensity has decreased up to 2020 in the base case which is a sign of economic efficiency as more efficient technologies are in place under

carbon tax scenario and after 2020, energy intensity showing a mix trend up to 2050 in the base case as well as in all carbon tax scenarios.

5.4.4 Green House Gases Emission under Renewable Portfolio Supply and Carbon Tax Scenario

Environmental emissions are decomposed into green house gases emissions e.g. CO₂, CH₄, CO, SO₂, NO_x, and PM₁₀. According to Fig-17, total cumulative green house gases emissions is reduced from 165 million tons in base case to 151 million ton in RPS50 scenario i.e. there is 9% reduction in green house gases emissions under renewable portfolio supply scenario which quite significant. As can be seen from Fig-18, total cumulative green house gases emissions is reduced from 72 million tons in base case to 19 million ton in CT30 scenario which is significant reduction in green house gases emissions under carbon tax scenario.

All these facts imply that renewable portfolio supply and carbon tax policy can be used as a combined policy options for the enhancement of energy security in case of Pakistan.

Fig 13

Vulnerability under Renewable Portfolio Supply Scenario

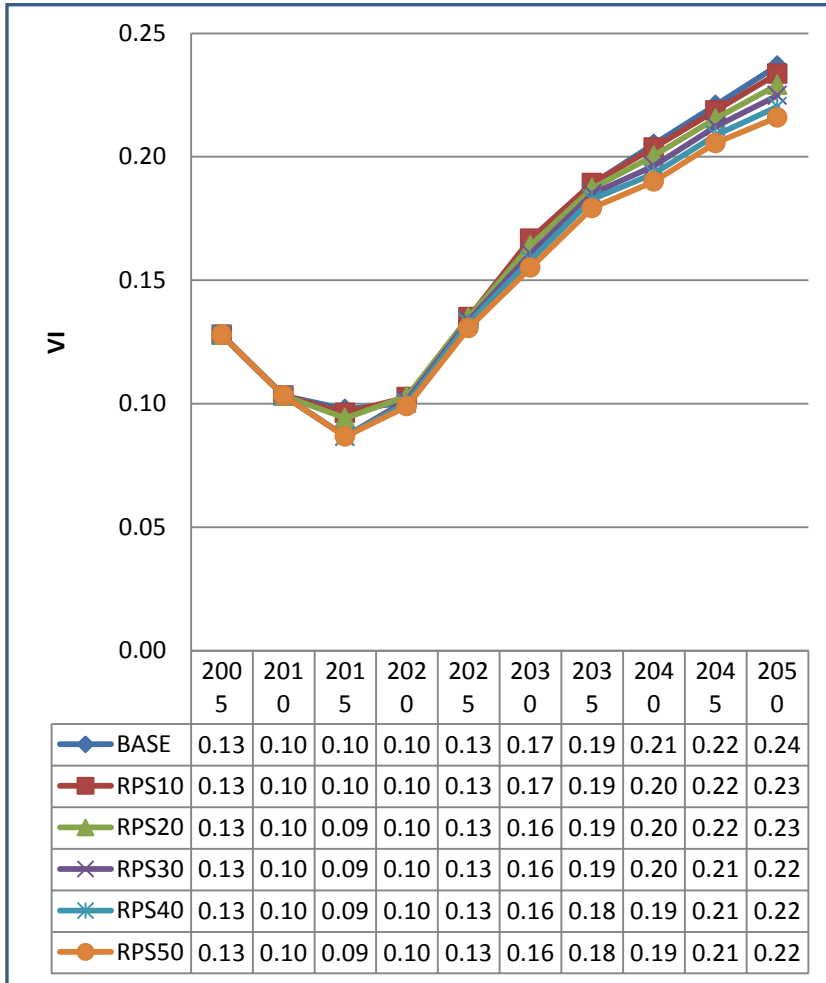


Fig 14

Vulnerability under Carbon Tax Scenario

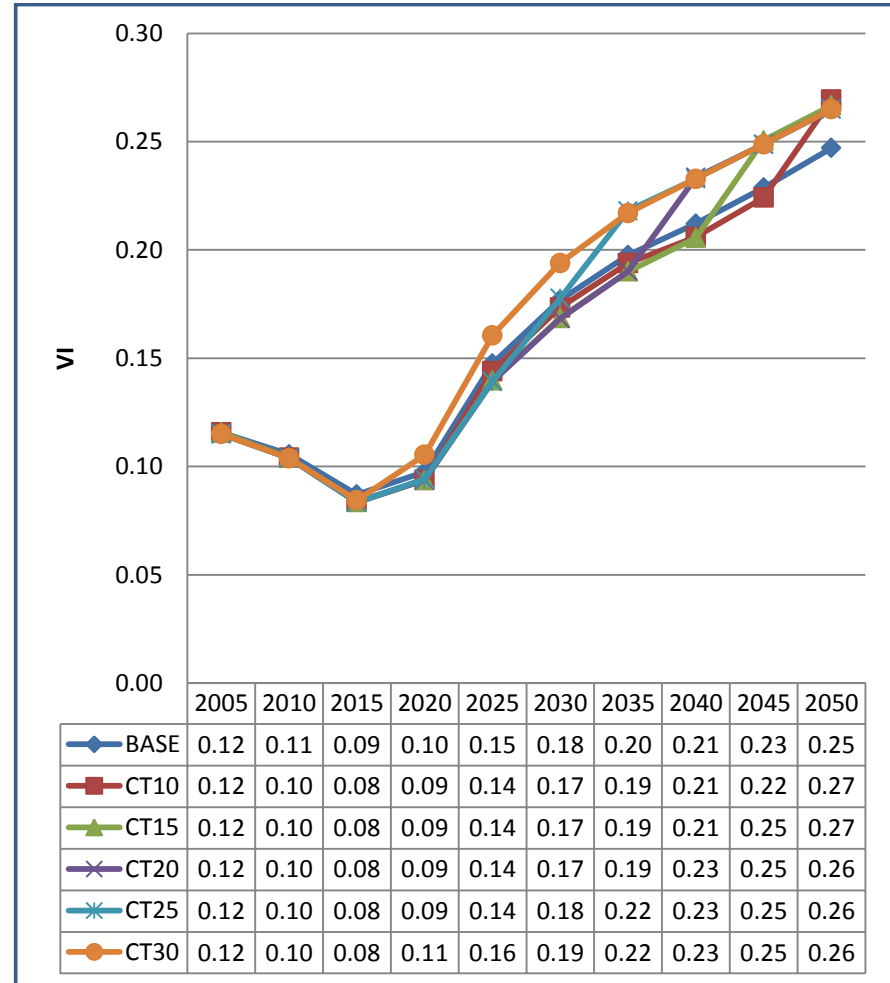


Fig 15

Energy Intensity under Renewable Portfolio Supply Scenario

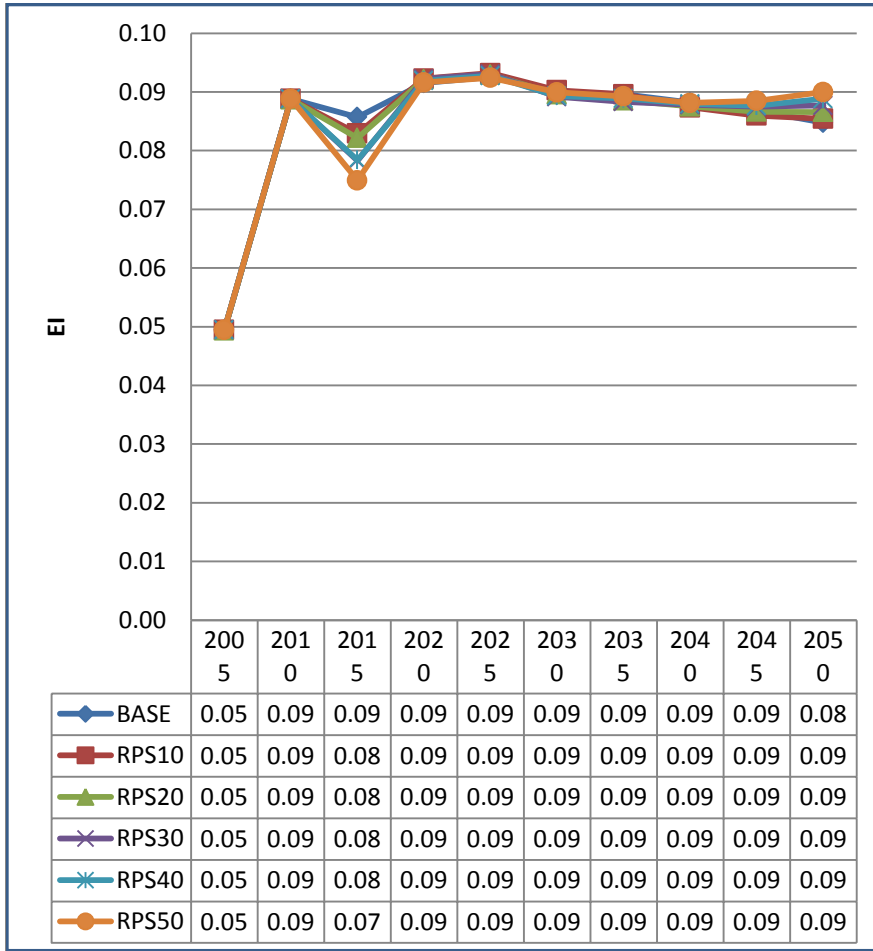


Fig 16

Energy Intensity under Carbon Tax Scenario

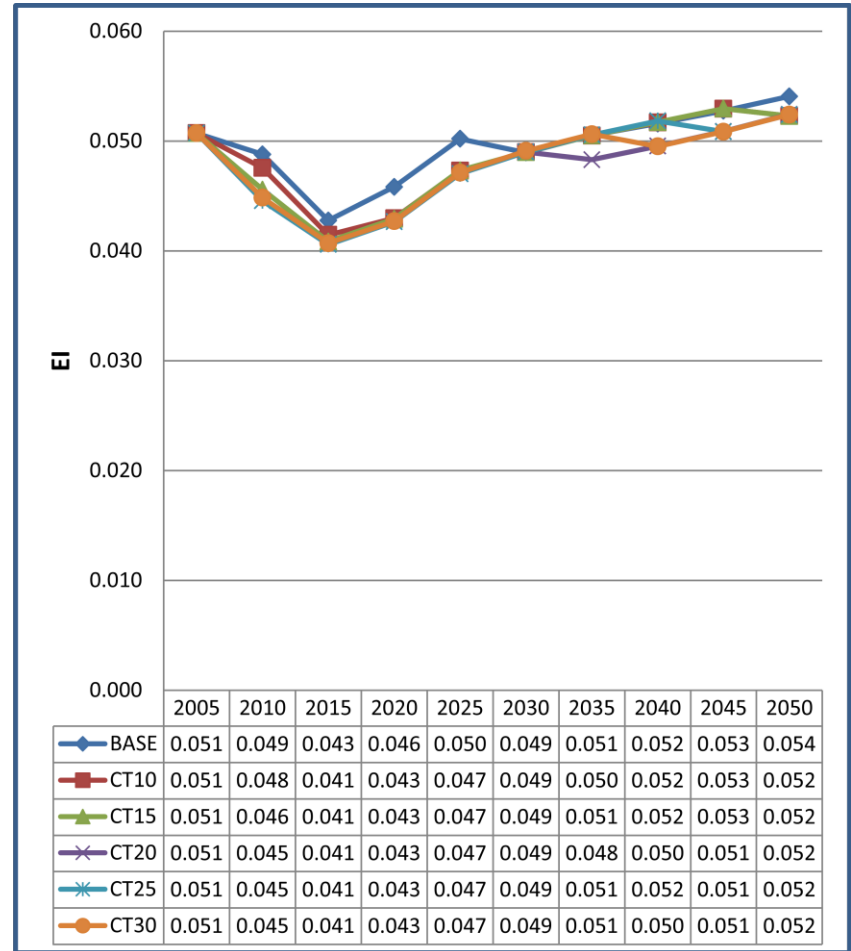


Fig 17

**Green House Gas Emission under
Renewable Portfolio Supply Scenario**

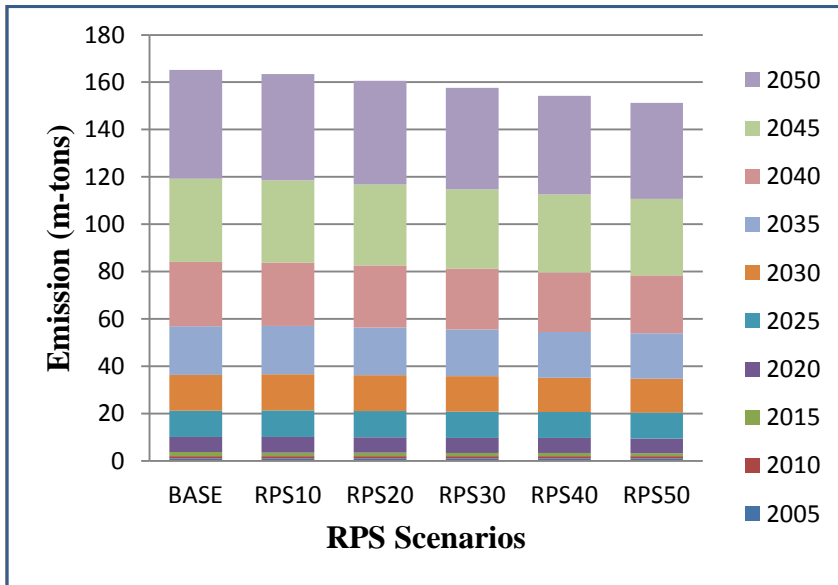
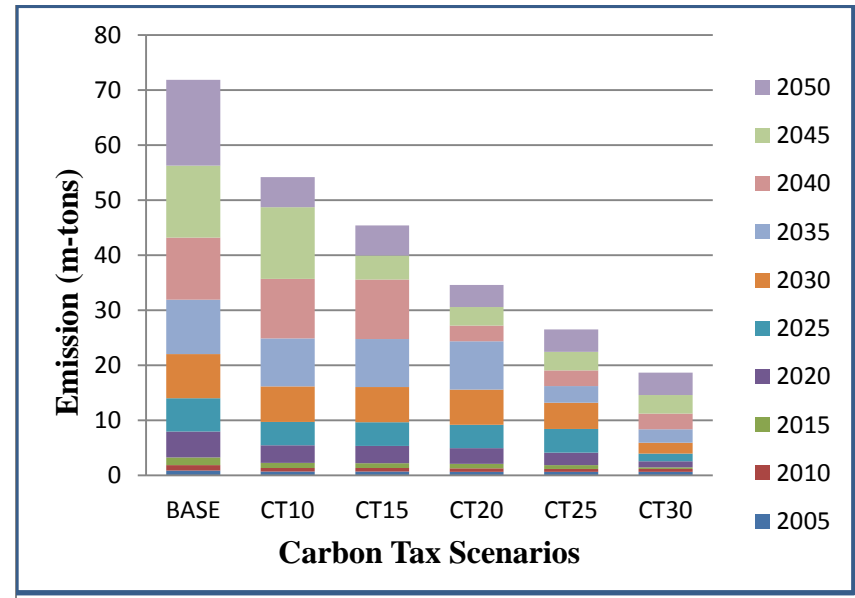


Fig 18

**Green House Gas Emission under
Carbon Tax Scenario**



6. Conclusions

This paper investigates the effects of renewable supply portfolio and carbon tax policies 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.

Renewable Portfolio Supply (RPS) is an important policy option to improve energy security. Renewable energy promotion is used to reduce emission, promote local energy sources and improve energy security through reducing energy dependency and diversification of energy sources. All the energy security indicators reflected better position under renewable portfolio supply scenarios; therefore Renewable Portfolio Supply (RPS) may be a suitable policy option for energy security improvement in the long term.

Carbon tax is an indirect policy option for energy security enhancement working through emission reduction. Imposing tax on carbon emission will alter the primary energy supply mix, more efficient fuel and technologies will be switched with less efficient fuel and technologies. This will reduce the primary energy demand and lead to improve energy security. Therefore Carbon Tax Policy may be a suitable policy option for energy security improvement in the long term.

Under Renewable Portfolio Supply (RPS) and Carbon Tax scenarios, Green House Gases (GHG) emissions are reduced to a significant level. This reduction in GHG emission is a sign of environmental security. So these two policy options are not only enhancing energy security, but also ensuring environmental security.

Appendix-A End-use Demand Technologies

Sector		End-use Demand Technologies
Agriculture		Tractors and Electric Motors
Commercial		AC, Lighting, Refrigerators, Thermal Use and Other Electric Appliances
Industrial		Cement, chemical, electricity, equipment, food, paper, steel, sugar, textile, others.
Residential		Air-conditioning, cooking, fan, iron, lighting, refrigerator, TV and other electric appliances.
Transport	Air Passenger	Air plane
	Air Freight	Air Plane
	Water Freight	Ship
	Rail Passenger	Locomotive rail
	Rail Freight	Locomotive rail
	Road Passenger	Car, bus, van, pickup, taxi, three-wheelers, two-wheelers
	Road Freight	Trucks, Tankers, Pickups

Appendix-B Conversion Technologies

Technology	Fuel Type
Power Generation	
Hydro	
a) Hydro	Reservoir
b) Hydro	Canal
Fossil Fuels	
a) Fluidized bed combustion(FBC)	Coal
b) Gas Turbine	Gas and HSD
c) Combine Cycle	Gas and HSD
d) Gas Turbine	Gas
e) Steam	Dual Fuel Combustion (Gas + FO)
f) Oil Fired	Fuel Oil
g) Gas Turbine Combine Cycle	Gas and FO fired Gas and HSD oil Fired
Nuclear	
a) Nuclear Power Plant	Uranium
Renewable	
Solar Photovoltaic, Solar Thermal, Wind Turbine, Mini Hydro	

Process Technologies	
a) Oil refinery	Crude Oil
b) Gas Processing Plant	Natural Gas

Appendix-C Model Formulation

Objective Function of the Integrated Energy System Cost Model.

The objective function is the sum over all of the discounted present value of the stream of annual costs incurred in each year of the horizon (no reference for this?). Therefore:

$$NPV = \sum_{r=1}^R \sum_{t=1}^{t=NPER} (1+d)^{NYRS \cdot (1-t)} \cdot ANNCOST(r, t) \cdot (1 + (1+d)^{-1} + (1+d)^{-2} + \dots + (1+d)^{1-NYRS}) \quad (1)$$

where, NPV is the net present value of the total cost for all regions, $ANNCOST(r, t)$ is the annual cost in region r for period t , d is the general discount rate, $NPER$ is the number of periods in the planning horizon, $NYRS$ is the number of years in each period t , R is the number of regions.

In order to minimize total discounted cost, the MARKAL model must satisfy a number of constraints. These constraints show the physical and logical relationships to describe the associated energy system.

a) Satisfaction of Energy Service Demands

For each time period t , region r , demand d , the total activity of end-use energy technologies must be at least equal to the specified demand. Hence:

$$\sum_k^{all\ d} CAP(r, t, k) \geq D(r, t, d) \quad (2)$$

where $CAP(r, t, k)$ is the installed capacity of technology k , in period t , in region r , $D(r, t, d)$ is the energy demand for end-use d in region r , in period t .

b) Use of Capacity

In each time period, the model may use some or all of the installed capacity according to the technology availability factor (AF) i.e. the model may utilize *less* than the available capacity during certain time-slices, or even throughout one whole period. Therefore, the activity of the technology may not exceed its available capacity.

$$ACT(r, t, k, s) \leq AF(r, t, k, s) CAP(r, t, k) \quad (3)$$

where $ACT(r, t, k, s)$ is the activity level of energy technology k , in period t , in region r , for time slice s , $AF(r, t, k, s)$ is the availability parameters.

c) Demand–Supply of Energy Balance

For each commodity c , time period t , region r , this constraint requires that the disposition of each commodity may not exceed its supply.

$$\sum_k Output(r, t, k, c) ACT(r, t, k, s) + \sum_l MINING(r, t, c, l) + \sum_l FR(s) IMP(r, t, c, l) \geq \sum Input(r, t, k, c) ACT(r, t, k, c, s) + \sum_l FR(s) EXP(r, t, c, l) \quad (4)$$

where $Output(r, t, k, c)$ is the amount of energy commodity c , produced per unit of technology k in region r in period t , $MINING(r, t, c, l)$ is the quantity of energy commodity c extracted in region r at price level l in period t , $FR(s)$ is the fraction of the year covered by time-slice s , $IMPORT(r, t, c, l)$ is the quantity of energy commodity c , price level l , exogenously imported or exported by region r in period t , $Input(r, t, k, c)$ is the amount of energy commodity c required to operate one unit of technology k , in region r and period t , $EXPORT(r, t, c, l)$ is the quantity of energy commodity c , price level l , exogenously imported or exported by region r in period t .

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