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A Computable General Equilibrium (CGE) Approach for Linking Energy Security and Primary Energy Supply Reduction Targets in Pakistan

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Abstract

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Keywords: Primary Energy Supply Reduction Targets, Energy Security, Computable General Equilibrium (CGE) Modelling, Pakistan

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Title

A Computable General Equilibrium (CGE) Approach for Linking Energy Security and Primary Energy Supply Reduction Targets in Pakistan

Contents

Abstract

This study examines the effects of reducing primary energy supply by 5%, 10%, and 15% through policy interventions from 2005 to 2050 on energy resource diversification, energy and oil import dependency, environmental emissions and energy security in Pakistan. Applying a CGE framework, the study finds that policy scenarios lead to decrease in cumulative primary energy supply, a rise in renewable energy, and a drop in greenhouse gas emissions. The results also show improved energy security, with a reduction in net energy import dependency, a decrease in net oil import dependency and a increase in energy resource diversification. These findings suggest that setting primary energy supply reduction targets could strengthen energy security in Pakistan.

Keywords:

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Introduction

Energy security is considered to be improved through various direct and indirect policy options including restricting primary energy imports, reducing primary energy supply, imposing carbon emissions tax, renewable portfolio standards etc. Reducing primary energy supply (PES) is an explicit strategy to enhance energy security (ES) via diversification of energy sources that leads to demand side management, technological innovations and increased energy efficiency. Thus, it is critical to look into the consequences of reducing primary energy supply on energy import dependence, energy resource diversification, vulnerability and intensity of energy sector, and environmental emissions (Anwar 2016; Anwar 2010).

Pakistan meets only 1/6th of its oil consumption through domestic production and relies on imports to fulfill 1/3rd of its overall energy needs. This suggests that Pakistan is a net importer of energy and that its energy demand exceeds its supply from internal resources (Pakistan Economic Survey 2006-2023, Pakistan Energy Yearbook 1995-2005).

An extensive policy and market-based analysis is necessary to evaluate the aforementioned aspects of the energy sector. By analyzing the advantages and disadvantages of various scenarios of primary energy supply reduction targets, the suggested study takes a step in the right direction.

The energy sector in Pakistan has both a significant potential in several sources and a noticeable disparity amongst the energy supply and demand. While hydropower has an estimated potential of over 42 GW, only 6.5 GW is currently exploited, showing a large amount of room for expansion. Given Pakistan economic difficulties, it is difficult to maintain imports of fossil fuels, which could exacerbate the country's shortcomings in energy security (Asif, 2008; Mirza et al. 2006; Mirza et al., 2007; Sahir & Qureshi, 2006; Sahir & Qureshi, 2006a).

Despite being a net energy importer, Pakistan lacks a comprehensive study on how reduced primary energy supply could impact energy security, including import dependency, resource diversification, energy sector vulnerability, GHG emissions, and import costs.

The long-term (2005-2050) implications of various degree of primary energy supply reduction targets are examined in this study for Pakistan. Using a computable general equilibrium (CGE) model, this study assesses the impact of three primary energy supply reduction targets (Five, Ten, and Fifteen percent) for 2005-2050 on Pakistan total primary energy supply (TPES), total final energy consumption (TFEC), ES, and environmental emissions.

The paper is structured as follows: Section 2 reviews Pakistan energy outlook and options for energy security policies. Section 3 describes the methodology, model setup, and scenarios. Section 4 evaluates the effects of primary energy supply reduction scenarios, and Section 5 states the major conclusions.

Pakistan Energy Prospectives and Energy Security Policy Options

The economy of Pakistan is divided into five sectors based on energy consumption including industrial, transport, residential, commercial and agriculture. The industrial sector is the largest energy consumer, using 42% of the total energy. The transport sector follows with 22%, the residential sector with 21%, the commercial sector with 6%, and the agriculture sector with just 2% Pakistan Economic Survey (2022-23).

The energy sector in Pakistan relies mostly on imports of petroleum products, gas, coal and crude oil. Pakistan Economic Survey (2022-23) indicates that during 2021-2022, the country imported 84.44 (76%) million barrels of crude oil, produced 26.08 (24%) million barrels of crude oil, extracted 1,237,251 (75%) million cubic feet of gas domestically, imported 405,925 (25%) million cubic feet of gas, imported 13.19 (55%) million tons of petroleum products, and produced 10.99 (45%) million tons of petroleum products domestically. Additionally, during 2021-22, 32.53 (77%) million tons of coal were imported, while 9.60 (23%) million tons of coal was produced domestically.

Pakistan's primary energy supply mix includes oil, natural gas, coal, electricity, nuclear, and renewable resources. Historical data shows that oil and gas make up 66% of the mix, coal contributes 13%, imported LNG 9%, hydroelectricity 8%, nuclear 3%, and renewable 1%. Domestic oil production only meets 16% of demand, while oil imports fulfill 33% of total energy demand, highlighting a significant energy supply deficit in the economy.

To mitigate the adverse effects of oil imports, and satisfy energy demand, Pakistan should prioritize the development of its untapped renewable energy resources, including hydro, solar, and wind power, which are both sustainable and economically beneficial. Government of Pakistan announced energy policy in 1994 and 2002 to incorporate different energy resources in the PES mix. The primary goals of these strategies were to enhance power generation, promote the use of domestic alternative resources, and manage environmentally friendly emissions. Numerous strategic possibilities intended for progressing ES are listed in Table-1.

Table 1

Policy Options and Energy Security Indices

Energy Policy Option to Enhance Energy Security		
▪ Total Primary Energy Reduction		
▪ Energy Import Reduction		
▪ Renewable Energy Promotion		
▪ Carbon Tax		
▪ Energy Conservation and Efficiency		
▪ Diversification		
	Energy Security Indicators	
Energy Demand (ED)	ED1-	Energy Intensity (E-I)
	ED2-	Oil Intensity (O-I)
	ED3-	Oil Use per capita (O-U-P-C)
	ED4-	Energy Use per capita (E-U-P-C)
	ED5-	Share of transport sector
	ED5-	Shares of oil use in Transport Sector per total oil use
Availability of Energy Resources (AER)	AER-1	Shannon-Wiener Index (SWI)
	AER-2	Diversification of Primary Energy Demand (DoPED)
Energy Market (EM)	EM1-	Net Energy Import Ratio (N-E-I-R)
	EM2-	Vulnerability Index (V-I)
	EM3-	Net Oil Import Dependency (N-O-I-D)

Source: Anwar (2016)

Empirical Approach:

Model Setup

Computable General Equilibrium (CGE) modeling is an economic tool used to stimulate how an economy responds to policy changes or external shocks. It helps policymakers and analysts assess the potential impacts on various sectors and overall economic growth (Shoven & Whalley, 1984; Dixon & Parmenter, 1996; Wing, 2004; Thurlow, 2008).

Pakistan faces energy deficiency and relies heavily on imported fossil fuels, raising concerns about energy security. Policymakers are exploring ways to improve energy security while supporting economic growth. CGE modeling can be a valuable tool for assessing the potential impacts of various policies on the country's economy and energy security (Kemal et al., 2003; Siddiqui et al., 2008).

This study has adopted the CGE model of Pakistan developed by Farooq (2015) including six building blocks: production block, income and expenditure block, investment block, pricing block, macroeconomic closure block, and market clearing block.

There are seven nested tiers in the production block (Figure 1), while the income and expenditure block consists of households (Figure

2), firms, government, and the rest of the world. The firms produce goods and services and sell them to the three institutions (Figure 3) – households, government, and international trade. The price block includes national and international trade prices (import and export prices) as well as the consumer price index. Three main types of closures are used: General government closure, external closure/current account closure, and Saving-investment balance.

The CGE model incorporates an energy and emission module to consider the impact of energy consumption, measured in physical units (PJ), on local and global pollutants. The amount of energy consumed is determined by dividing the energy utilization in financial units by the unit price for a certain fuel (Million Rs./PJ).

The benchmark dataset for this study is the Social Accounting Matrix (SAM) of Pakistan for the base year 2005 [Farooq 2005]. This SAM was created using various data sources, including the 1990-91 input-output table, studies by the Federal Bureau of Statistics from 2005, the Pakistan Economic Survey (GOP 2008), tax information from the Federal Board of Revenue (FBR 2007), trade data from the State Bank of Pakistan, and energy production and consumption statistics from the HDIP (2006, 2009, 2010). The construction of the SAM for 2005 involved a systematic step-by-step procedure (Pyatt, 1985, 1988, 1990; Pyatt & Round; 1977, 1979, 1985; Thorbecke, 2000).

The model in this study includes both static and dynamic components. The static part focuses on one-time decisions, while the dynamic component captures the long-term economy-wide effects of unexpected policies in Pakistan. The recursive dynamic module determines sequential equilibria, with the benchmark year as the first equilibrium. Exogenous factors like capital stocks, demographic changes, and improvements in factor efficiency are used to determine equilibrium over time.

Scenarios Description

A baseline scenario and three sub-scenarios are developed to ensure energy security while reducing PES.

1. A 5% reduction in primary energy supply as contrasted to the benchmark scenario starting from 2005 onwards (henceforth "TPES05"),
2. A 10% reduction in primary energy supply as contrasted to the benchmark scenario starting from 2005 onwards (henceforth "TPES10"),
3. A 15% reduction in primary energy supply as contrasted to the benchmark scenario starting from 2005 onwards (henceforth "TPES15").

The scenarios are evaluated from three energy security perspectives: energy demand, resource availability, and the energy market. Energy demand is measured by four indicators, resource availability by two indicators, and the energy market by three indicators in Table 2.

Table 2

Selected Energy Security indicators

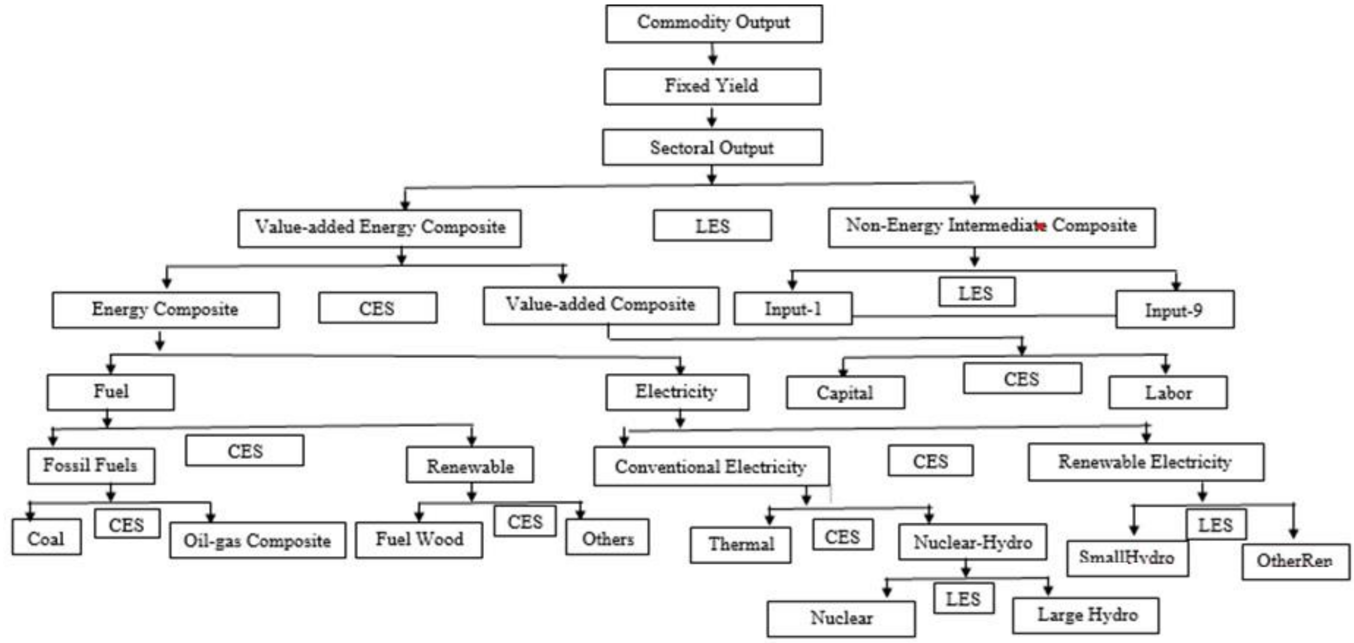
Energy Demand	
1	Energy Intensity (E-I)
2	Oil Intensity (O-I)
3	Oil Use per capita (O-U-P-C)
4	Energy use per capita (E-U-P-C)
Availability of Energy Resources	
1	Shannon Weiner Index (SWI)
2	Diversification of primary energy demand

Energy Demand	
	(DOPED)
Energy Market	
1	Net Energy Import Ratio (N-E-I-R)
2	Vulnerability Index (V-I)
3	Net Oil Import Dependency (N-O-I-D)

Source: Anwar (2016)

Figure 1

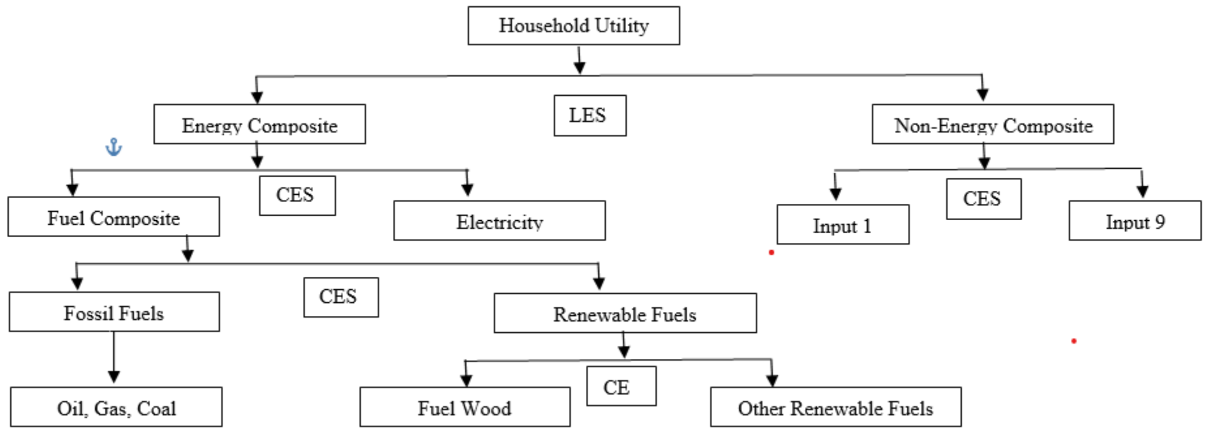
CGE Model Adaptation Layout (Production Sector)



Source: Farooq (2015), Shoven & Whalley (1984), Dixon & Parmenter (1996), Wing (2004), Thurlow (2008).

Figure 2

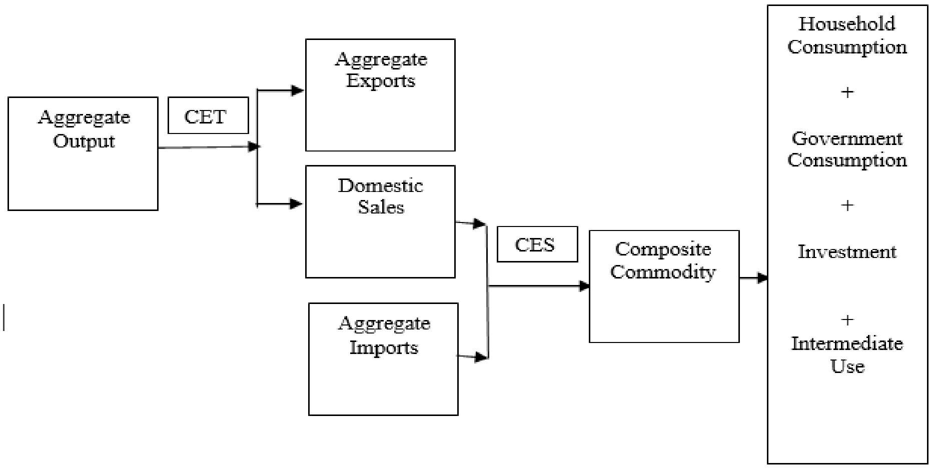
CGE Model Adaptation Layout of Household Utility



Source: Farooq (2015), Shoven & Whalley (1984), Dixon & Parmenter (1996), Wing (2004), Thurlow (2008).

Figure 3

CGE Model Adaptation Layout of Flow Commodities



Source: Farooq (2015), Shoven & Whalley (1984), Dixon & Parmenter (1996), Wing (2004), Thurlow (2008).

Results and Discussion:

Variations in Energy Supply, Final Consumption, and Environmental Emissions

The variations in total primary energy supply from 2005 to 2050 are reflected in Figure-4, showing a significant decline in the fossil fuel percentage in total primary energy supply including gas, oil, and gas from 2005 to 2050 as contrasted to the benchmark scenario, while the shares of renewable supplies have increased in all PES reduction targets. Specifically, the shares of oil have substantially decreased as compared to the shares of other fossil fuels. The increased shares of renewable resources in TPES and the declining shares of fossil fuels indicate the enhancement of ES in all the PES reduction targets from 2005 to 2050.

The variations in the TFEC from 2005 to 2050 are portrayed in Figure 5, revealing a substantial decline in the TFEC in the agriculture sector, industrial sector, services sector, and other sectors under the total primary energy supply reduction targets as contrasted to the benchmark scenario. The TFEC in the agricultural sector has declined very sharply in all total primary energy supply reduction targets, as compared to the benchmark scenario. This decline in TFEC is due to the adoption of fuel-efficient technologies and modernized methods used in agriculture sectors. The TFEC in the industrial sector, services sector, and other sectors has declined gradually in all total primary energy supply reduction targets as contrasted to the benchmark scenario. The decline in total final energy consumption may be a result of the modernized and fuel-efficient technologies in all these sectors. The decline in the total final energy consumption due to fuel-efficient technologies in all these sectors is a sign of enhanced energy security from 2005 to 2050.

Table 3 shows a substantial decrease in environmental emissions, including GHGs and local pollutants, under primary energy supply reduction targets. The most notable reductions are in CO_2, followed by SO_2, NO_x, CO, CH_4, N_2O, PM_{10}, and NMVOC. This emission reduction is largely due to decreased final energy consumption, reflecting enhanced energy security from 2005 to 2050 under the energy supply reduction policy.

Figure 4

Cumulative Primary Energy Supply (PJ) in 2005-2050

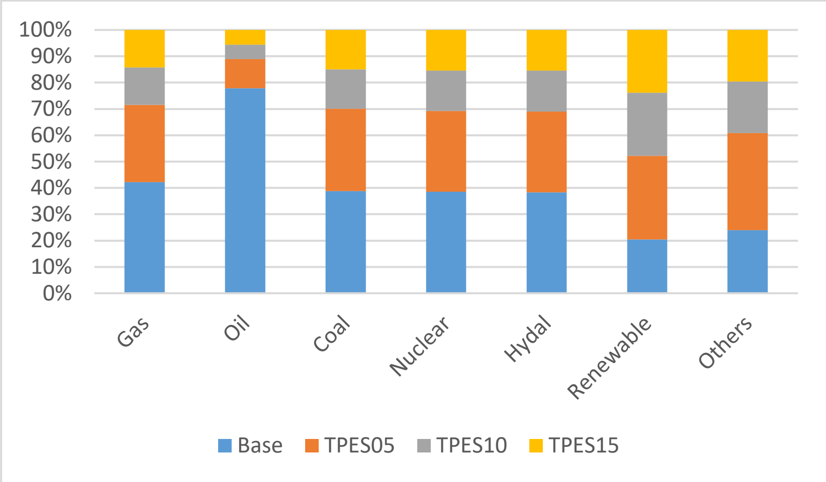


Figure 5

Cumulative Total Final Energy Consumption (PJ) in 2005-2050

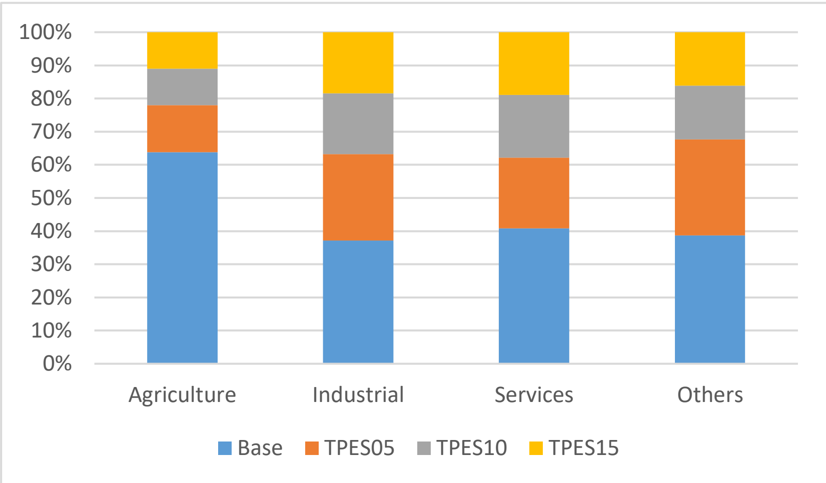


Table 3

Total Emission during 2005-2050 (10^3 tons)

	CO_2	SO_2	NO_x	CO	CH_4	N_2O	PM_{10}	NMVOC
Base	1874.69	7.18	11.87	2.72	0.08	0.03	1.89	0.07
TPES05	1264.89	4.77	7.18	1.59	0.05	0.02	1.21	0.05
TPES10	987.11	3.99	6.02	1.35	0.04	0.02	0.92	0.04
TPES15	901.35	3.79	5.51	1.35	0.04	0.02	0.92	0.04

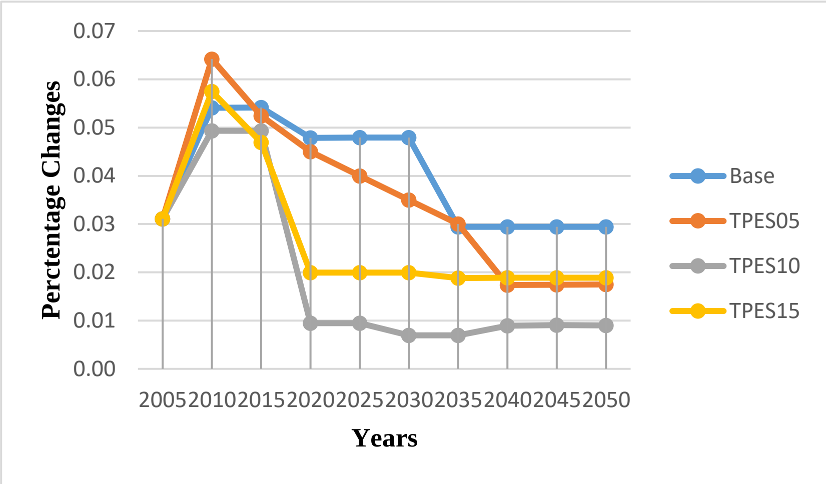
Variations in Energy Demand

The variations in energy demand are reflected by changes in ES indicators including E-I, O-I, O-U-P-C, and E-U-P-C. All these energy security indicators signify an improvement in ES under PES reduction targets from 2005 to 2050.

E-I measures the energy efficiency of an economy by comparing the relationship between energy consumption and GDP. A higher E-I indicates more expense in transforming energy into economic output, while a lower value reflects greater efficiency. The variations in energy intensity are shown in Figure 6, reflecting a significant decline in energy intensity during 2010-2050 signifying a long-term energy security enhancement. Energy intensity decreases from 0.03% in 2005 to 0.02% in 2050 across all energy supply reduction scenarios, indicating lower energy conversion costs, improved resource availability, and enhanced energy security.

Figure 6

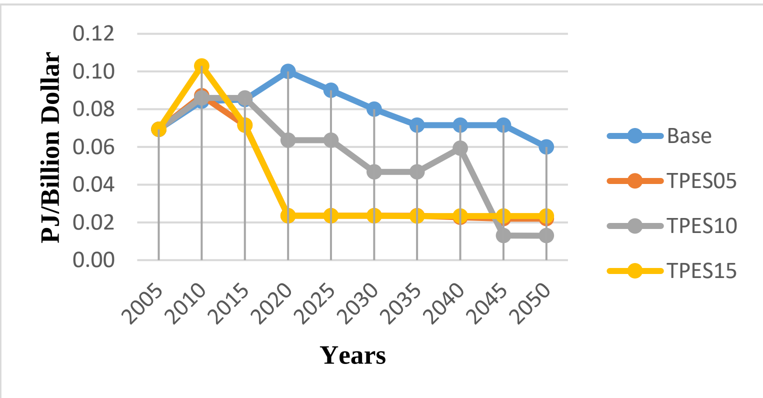
Variation in Energy Intensity (%)



O-l represents the proportion of a country's oil consumption to its economic output, reflecting how much oil is used to generate economic output. Higher oil intensity implies more oil is used per unit of GDP, indicating a higher oil dependency for economic output, while lower oil intensity indicates higher efficiency or diversification in energy resources. The variations in oil intensity are revealed in Figure 6, indicating a continuous decline in oil intensity during 2010-2050 demonstrating a long-term energy security enhancement. The value of oil intensity decreased from 0.07 petajoules per billion dollars in 2005 to 0.02 petajoules per billion dollars in 2050 during all the primary energy supply reduction scenarios. The decline in oil intensity implies a reduction in oil dependency and/or diversification in energy resources and subsequently an enhancement of energy security.

Figure 7

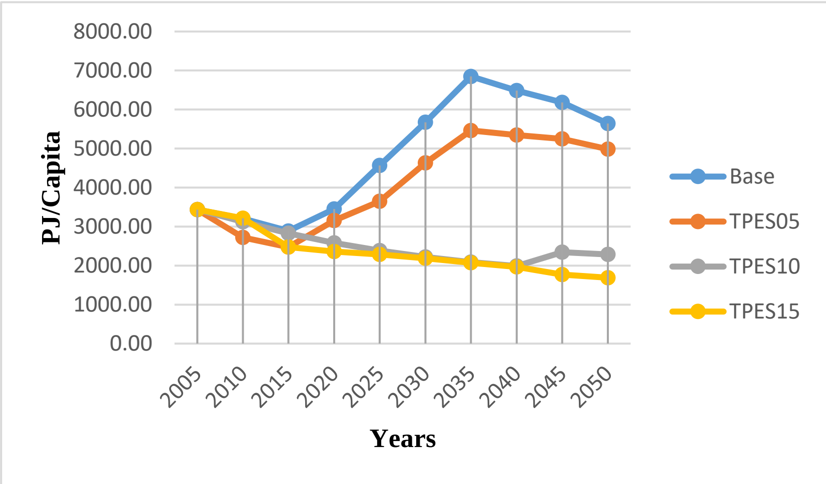
Variation in Oil Intensity (PJ/Billion Dollar)



O-U-P-C is the average oil consumption per capita in an economy. Higher oil use per capita indicates higher personal energy consumption, while lower oil use per capita denotes energy efficiency. The variations in oil use per capita are revealed in **Figure 6,** indicating a continuous decline in oil use per capita from 2005 to 2050 demonstrating energy security enhancement for a long time period. The value of oil uses per capita decreased from 3436.15 petajoules per capita in 2005 to 1689.56 petajoules per capita in 2050 during all the primary energy supply reduction scenarios. The decline in oil use per capita implies a reduction in oil dependency and/or diversification in energy resources and subsequently an enhancement of energy security.

Figure 8

Variation in Oil Use Per Capita

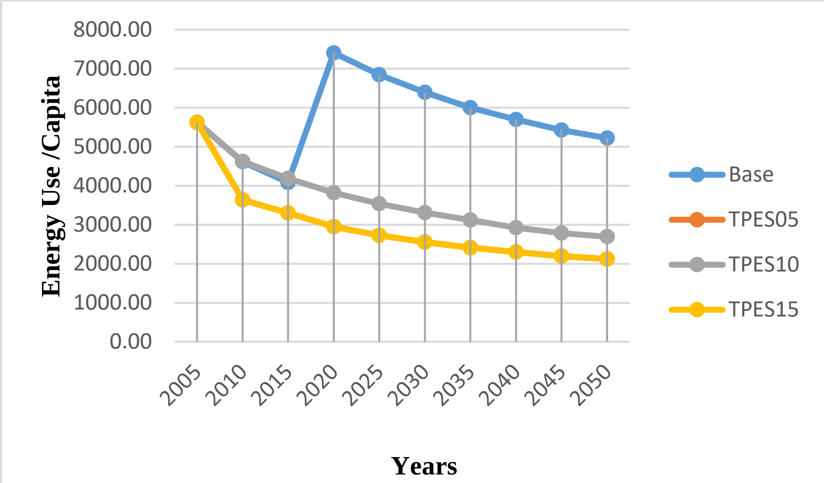


E-U-P-C is the average energy consumption per capita in an economy. Higher energy use per capita indicates higher personal energy consumption, while lower energy use per capita denotes low personal energy consumption. The variations in oil use per capita are revealed in **Figure 7,** indicating a continuous decline in energy use per capita from 2005 to 2050 demonstrating energy security enhancement for a long time period. The value of energy uses per capita decreased from 5625.31 petajoules per capita in 2005 to 2119.48 petajoules per capita in 2050 during all the PES reduction scenarios. The decline in energy use per capita implies a decline in energy reliance and/or diversification in energy resources and subsequently an enhancement of energy security.

The variations in energy demand were assessed through four energy security indicators. E-I, O-I, O-U-P-C, and E-U-P-C exhibited a continuous declining trend during the planning horizon 2005-2050, thus revealing an enhancement in energy security in all the primary energy supply reduction scenarios.

Figure 9

Variation in Energy Use Per Capita



Variations in Energy Resources Availability

Diversifying energy resources is crucial for improving energy security. The SWI and DoPED are employed to evaluate the diversification and availability of energy resources, with higher SWI estimates and lower DoPED estimates indicating a more diversified energy system. Variations in the diversification of energy resources through the use of SWI and DoPED are reflected in Figure-9 and Figure-10, revealing energy resource diversification from 2015 to 2050. Specifically, the values of SWI rise from 0.31 in 2005 to 0.32 in 2050, while the values of DoPED decline from 0.84 in the base case to 0.62 in 2050 under the 15% primary energy supply reduction target (TPES15). The rising value of SWI and declining value of DoPED reflects more diversification and/or availability of energy resources during 2005-2050 and consequently implying energy security.

Figure 10

Variation in Diversification - SWI

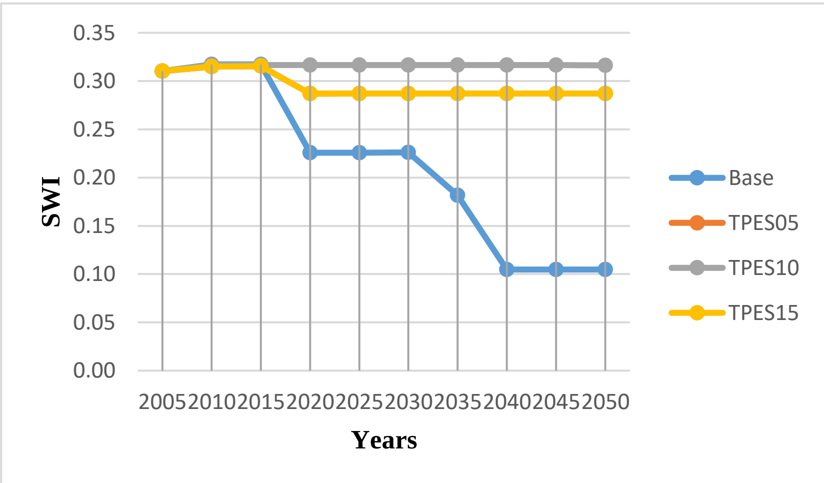
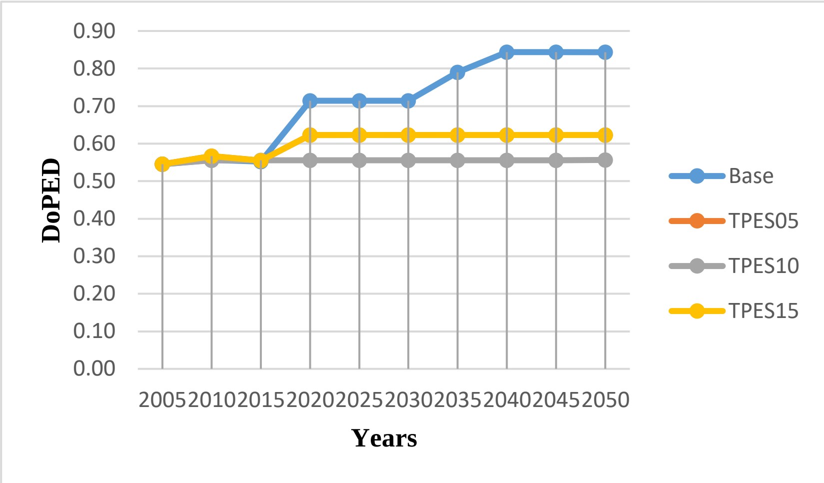


Figure 11

Variation in Diversification - DoPED



Variations in Import Dependency and Vulnerability

Energy market analysis evaluates import dependency and system vulnerability using the N-E-I-R, N-O-I-D, and V-I. The variations in energy import dependency and oil dependency are portrayed in Figure-11 and Figure-12**,** revealing a continuous decline in energy import dependency and oil dependency throughout the primary energy supply reduction targets as contrasted to the benchmark scenario during the planning horizon 2005-2050. Specifically, energy import dependency declined from 93% as contrasted to the benchmark scenario to 68% in the 15% primary energy supply reduction target in 2050. Similarly, N-O-I-D decreased from 135% in the base case scenario to 118% in the 15% PES reduction target in 2050. The decline in energy import dependency and net oil import dependency signifies an enhancement in energy security from 2005 to 2050.

The variations in vulnerability of the energy sector are illustrated in **Figure-13,** demonstrating a consistent decline in vulnerability in all the PES reduction targets during 2005-2050 as contrasted to the benchmark scenario. Specifically, the value of the vulnerability index declined from 25% in the base case scenario to 7% in the 15% PES reduction target in 2050, showing an enhancement in energy security during 2005-2050.

Figure 12

Variation in Import Dependency – NEIR (%)

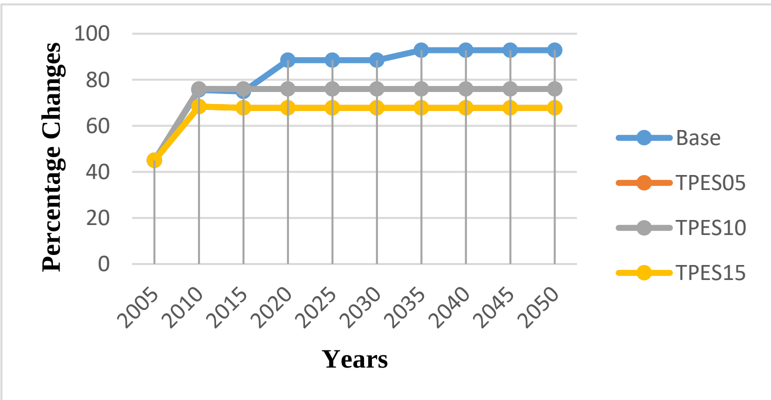


Figure 13

Variation in Import Dependency – NOID (%)

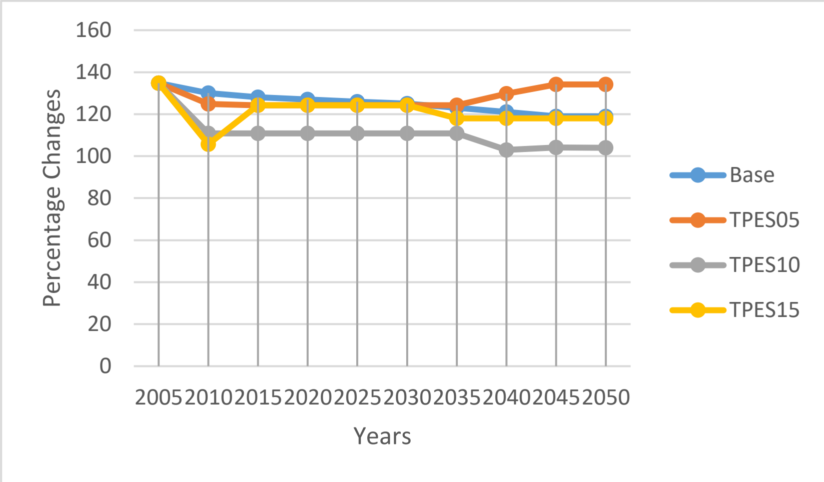
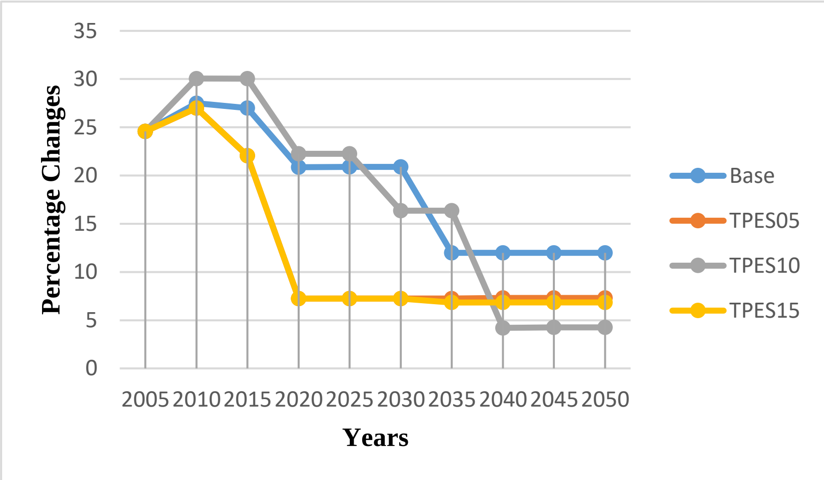


Figure 14

Variation in Vulnerability - VI



Conclusions

This study examined the effects of reducing primary energy supply from 2005 to 2050 under three scenarios using a computable general equilibrium model, focusing on impacts on primary and final energy mix, emissions, and diversification of energy resources. This study assessed Pakistan's energy security from 2005 to 2050 using nine energy security indicators across three targets for reducing primary energy supply.

The variations in energy demand were assessed through four energy security indicators. Energy intensity decreases from 0.03% in 2005 to 0.02% in 2050 during all the primary energy supply reduction scenarios. Oil intensity decreases from 0.07 Petajoules per Billion Dollars in 2005 to 0.02 Petajoules per Billion Dollars in 2050. Oil use per capita decreases from 3436.15 PJ/Capita in 2005 to 1689.56 PJ/capita in 2050, and energy use per capita decreases from 5625.31 PJ/Capita in 2005 to 2119.48 PJ/capita in 2050 during all the primary energy supply reduction scenarios. All these indicators exhibited a continuous declining trend during the planning horizon 2005-2050, thus revealing an enhancement in energy security in all three primary energy supply reduction scenarios. The energy supply side saw increased resource diversification from 2005 to 2050, with a higher share of renewables in the primary energy mix, boosting energy security. Additionally, energy import dependency decreased by 12%, and vulnerability dropped by 7%.

The research concludes that, with policy measures, Pakistan's PES would decrease while renewable energy usage would increase, leading to reduced GHG emissions. Benefits include increased energy diversification, reduced environmental impact, and decreased import dependency and vulnerability, all enhancing energy security. Setting primary energy supply reduction targets could further strengthen Pakistan's energy security.

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