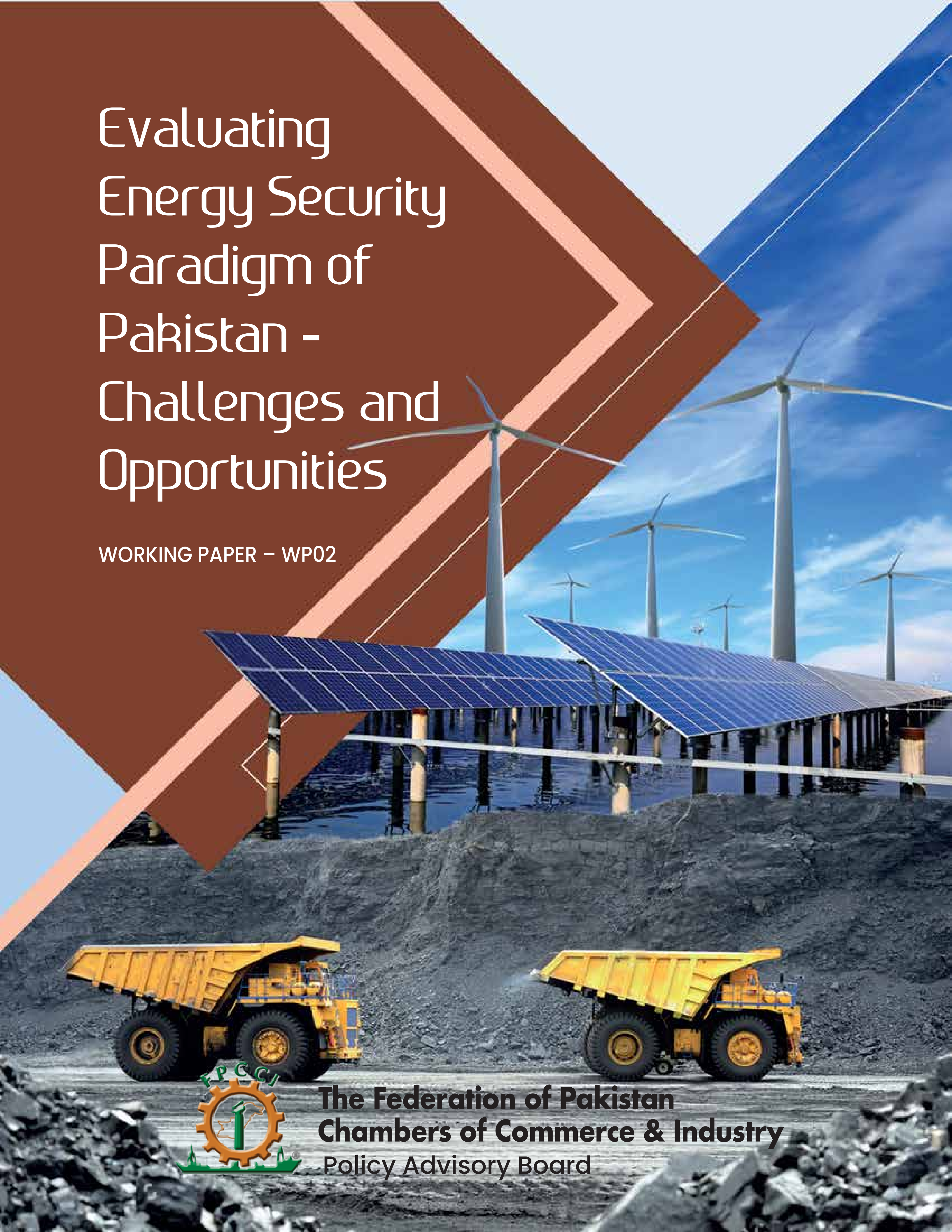
Evaluating Energy Security Paradigm of Pakistan - Challenges and Opportunities

WORKING PAPER – WP02



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Acronyms

PSES	Pakistan's Sustainable Energy Security
POL	Petroleum oil and liquid
EU	European Union
GOP	Government of Pakistan
MoE	Ministry of Energy
OGRA	Oil & Gas Regulatory Authority
NEPRA	National Electric Power Regulatory Authority
IPP	Independent Power Producers
DISCOs	Distribution Companies
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MW	Mega Watt
WEC	World Energy Council
GDP	Gross Domestic Product
TPEC	Total Primary Energy Consumption
TPEP	Total Primary Energy Production
SWI	Shannon-Weiner Index
COMCR	Crude Oil Market Concentration Risk
HDIP	Hydrocarbon Development Institute of Pakistan
PBS	Pakistan Bureau of Statistics
SBP	State Bank of Pakistan
PEY	Pakistan Energy Yearbook
BP	British Petroleum
OML	Oil Market Liquidity
IEA	International Energy Agency
PSO	Pakistan State Oil
TOE	Tons of Oil Equivalent
TOPSIS	Technique for Order Preference by Similarity to an Ideal Solution
CTL	Coal-to-Liquid technology
CTG	Coal-to-Gas technology
IGCEP	Indicative Generation Capacity Expansion Plan
WACOG	Weighted Average Cost of Gas
EV	Electric Vehicle
BRT	Bus Rapid Transit
NEECA	National Energy Efficiency and Conservation Authority
CTBCM	Competitive Trading Bilateral Contract Market
SSGCL	Sui Southern Gas Company Limited
SNGPL	Sui Northern Gas Pipelines Limited
UFG	Unaccounted for Gas
OMC	Oil Marketing Companies
WB	World Bank

Executive Summary

The energy supply chain plays a critical role in determining the energy security profile of a country. Energy-importing countries find themselves more vulnerable to geopolitical crises. Currently, Pakistan is facing energy supply disruptions, unaffordable energy bills, unwanted load-shedding, and depleting oil and gas reserves. These problems are a result of unsynchronized energy sector policies, the absence of an integrated energy plan, higher import dependency, and years of wrong policy measures.

In recent years' different measures were adopted by many countries to improve their energy security profile. However, in Pakistan, no such research or policy has been initiated to achieve energy security. This study is one of its kind which has evaluated the energy security paradigm of the country.

Pakistan's energy security profile can be divided into two stages: Beginning from 2013 till 2015, country's energy security improved in all dimensions, whereas during 2016 – 2021, it deteriorated substantially. The possible reasons for such decline were; unstable domestic energy prices, low utilization of indigenous resources, geopolitical instability, higher energy intensity, heavy reliance on imported fossil fuels, inconsistent economic growth, insufficient energy efficiency and conservation measures, inefficient energy infrastructure, and absence of integrated energy policy.

To identify possible ways to improve the energy security of the country, a **sensitivity analysis** has been conducted. Three different scenarios are employed to assess the energy security profile of Pakistan. In the first scenario, local production is increased, the second scenario allows for the 100% usage of local coal and, in the third scenario, 50% of electricity production is derived from non-fossil energy. The results indicated that implementation of the above three scenarios in isolation failed to improve the overall energy security profile of the country. Achieving energy security is a complex phenomenon that requires a comprehensive and integrated effort. Hence, the above scenarios were combined to quantify the synergized impact on the energy profile. The analysis showed that Pakistan should raise its local production, minimize the use of imported coal and produce at least 50% of its electricity from non-fossil fuel to achieve energy security.

To avoid further increase in energy security risk, a synchronized and more robust policy framework along with clear implementation is required. The only way forward is to implement aggressive plans to achieve 100% indigenization in power sector, substituting imported coal with Thar coal, rationalization of energy prices and energy demand, abolishment of cross-subsidization in energy sector to boost industrial and commercial activities, implementing the WACOG bill to curtail excessive use/wastage of natural gas in the residential sector along with gradual transfer to competitive energy markets, etc. In addition, Integrated Energy Plan should be developed to be implemented through an Energy Security Policy to improve synergy and cohesiveness among energy sub-sectors i.e. oil, gas, and power.

1 Introduction

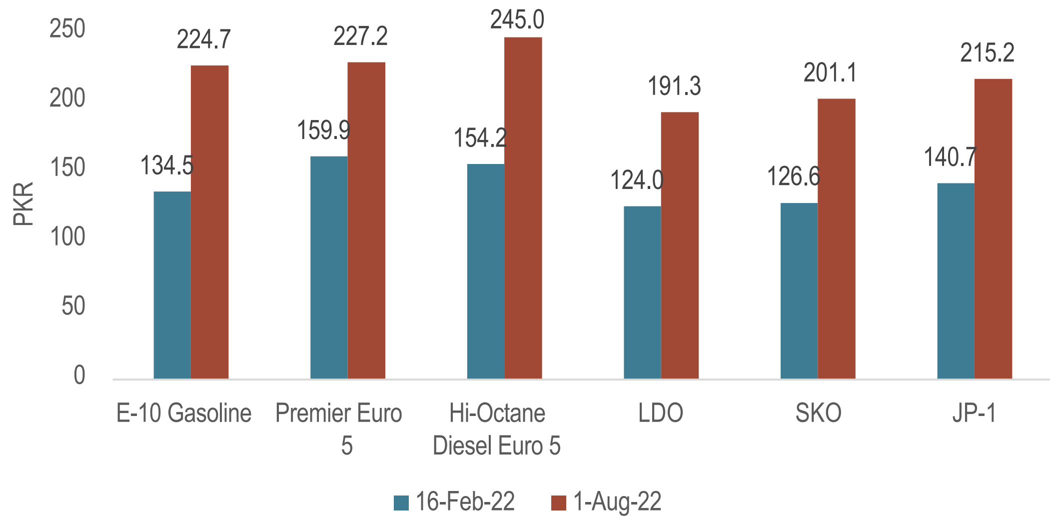
Energy is one of the key commodities traded in the current era that possesses the potential to impact almost all aspects of life. Its importance has significantly increased across all sectors and in modern times energy is considered one of the important inputs for economic growth. Today, an unprecedented energy crisis has gripped Pakistan. Supply crunch along with an increase in energy prices has negatively affected the economy and the people. Pakistan's long-term economic prosperity and the economic security of the country's 220.9 million citizens rely on energy security.

Energy is crucial for the modern economy, it almost drives every economic activity, from manufacturing goods to transport to communication to schooling, and thus has become an integral part of a country's development and prosperity. Overhaul in energy policies, import dependency, inefficient transmission lines, excessive energy consumption in the domestic sector, unavailability of public transport, and depleting foreign reserves has forced the country to become energy insecure. To develop an inclusive policy, it's vital that energy planning is integrated with other policies that drive economic growth, such as policies for agriculture and industries. The disintegrated policies has created an inefficient institutional framework thereby leading towards slowing down of investment flow in the sector. Even after 75 years of independence Pakistan doesn't have any integrated energy policy. Unfortunately, Pakistan does not have a single energy policy to synchronize power and oil and gas sector policies to achieve a single outcome.

In addition to this, the shift in international and regional politics plays a pivotal role in determining the supply and demand of fossil fuels in the international market. One of the prime examples to justify this notion is Russian – Ukraine conflict and its repercussions on the global energy supply chain. The European countries are directly affected due to this conflict; as natural gas prices have risen 10 times as compared to last year. In the UK, the price of a megawatt hour touched $590, which is five times that of August 2021. Countries like India, Pakistan, and Bangladesh are no exception as they had to import fossil fuels from external sources to meet their rising energy demand. The fossil fuel importing nations require a strong energy security policy to minimize international oil price shocks and become self-sufficient i.e. such countries are more vulnerable to external interventions in strategic policy.

The geopolitical shift affected the energy supply chain. As result, energy-importing countries are facing serious energy crises in the form of energy prices. In line with this, the POL prices in Pakistan have skyrocketed since Russia – Ukraine conflict. Figure 1, depicts the before and after Russia – Ukraine conflict prices for POL products in Pakistan.

Figure 1: POL prices before and after Russia-Ukraine conflict

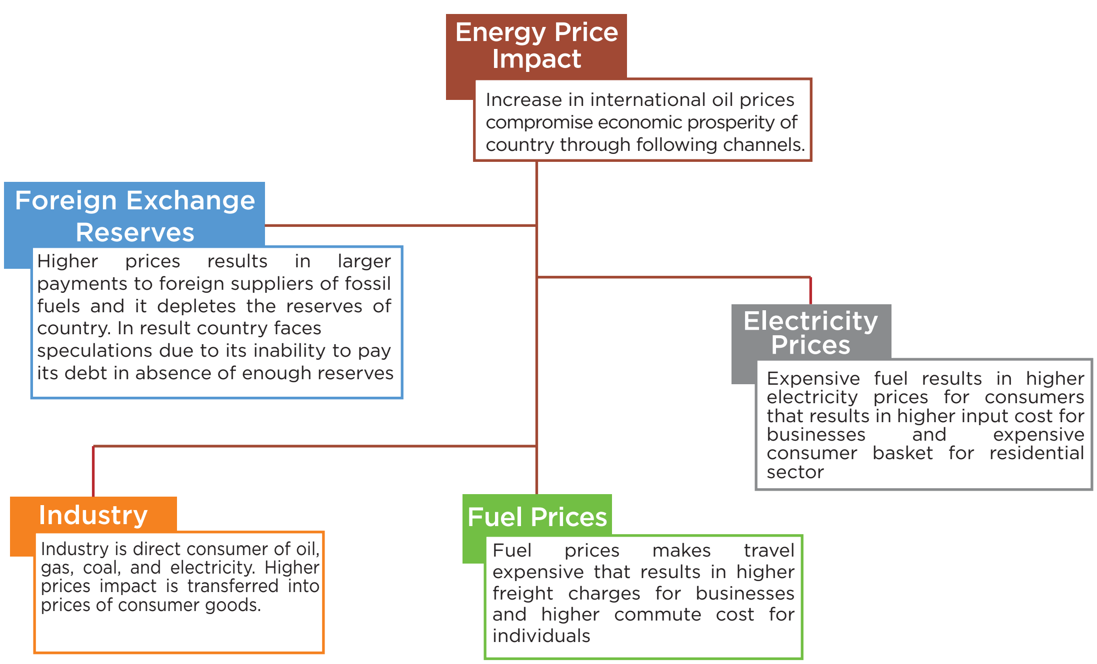


Source: (Pakistan State Oil, 2022)

1.1. Energy Prices and Economic well-being

Energy prices impact country's a growth, businesses, and economic well-being through four different channels: foreign exchange reserves; electricity prices; industry; and fuel prices. Figure 1, depicts the energy price impact.

Figure 2: Channels of energy price impact on economy



1.2. Economic Effects of Disruptions in the Supply of Energy

Disruption in the energy supply imposes both direct and indirect costs for businesses and households that bear higher energy prices. When disruptions in the supply of energy occur, Pakistani households and businesses suffer increase in costs by paying more for the same services and goods (such as gasoline, heat, and electricity) produced by that energy. The enormity of these costs hinges on the options that consumers have to lower their energy expenditures. In the near term, these consumers would reduce their expenditures in different ways – for example by switching to energy-efficient light bulbs, driving less or slowly, or vacationing away from home less frequently. In the long-term consumers has more time to make decisions as they will reduce energy expenditure in ways – for example by relocating to areas where travel expenditure is minimal, and less frequently use of air conditioner.

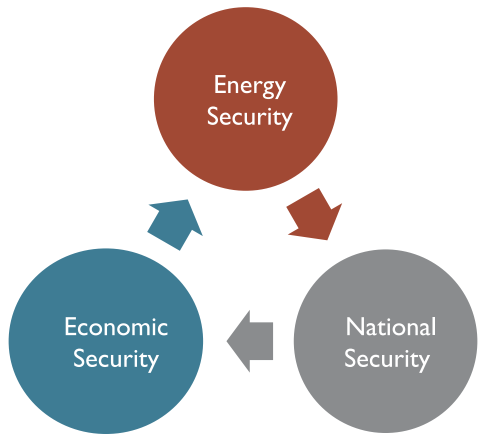
The higher expenditure on energy would cause households and businesses to reduce expenditure on other goods and services in the near term. The reallocation of expenditures in different sectors would cause an indirect cost for Pakistani households and businesses. As a result, the energy demand would decline in the near term. The higher energy prices would shift income and wealth within Pakistan from households and businesses to energy producers. The fossil fuel importing countries becomes more vulnerable due to international price increases that would benefit foreign suppliers of crude oil and gas. The higher payments to foreign producers put pressure further on the country's reserves and triggers inflation. The demand reduction would cause businesses to temporarily reduce investment and employment thereby diminishing household income and further lowering consumer spending.

1.3. Geo-Political Crises and their Ramifications on Economic Security

Energy resources are one of the important variables of a geopolitical mix in the modern political system. The reason for such a notion is the wave of industrial revolution, since then the dependence on fossil resources has increased significantly. Modern-day, industrialized nations require very stable energy supplies to ensure consistent improvement in economic growth and well-being.

Moreover, in the international political structure energy is considered to be a vital resource as it provides power to control political activities in the region. The presence of energy resources in abundance gave hegemony over other nations that suffer from an absence of fossil resources to drive their economy. It can be argued that the roots of all political conflict post-Cold War era lay in the control of natural resources rather than ideological as they used to be. Today, it has become very difficult to maintain a reliable energy supply due to geopolitical instability. This can be traced back to European Union (EU) countries. The Russian-Ukraine conflict has left the EU in a vulnerable position with soaring energy commodity prices, natural gas shortages, and unbearable damage to the industry. EU is not the exception in this, as many other countries came under heat due to the conflict. In Pakistan, energy prices soared to an all-time high which led to higher energy bills.

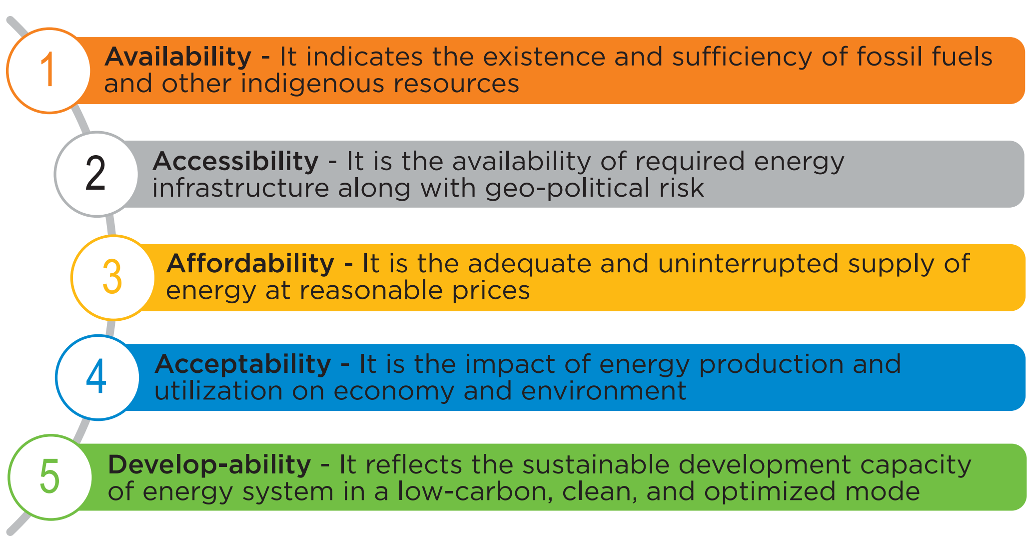
For many decades' fossil resources have helped countries to develop industries and boost their economic outlook at a global scale but at a cost of energy-importing nations. Currently, energy import nations are entangled in a paradigm that they don't have the option to substitute imported energy commodities with local commodities. Thus, it can be said that energy security has a strong correlation with economic security and national security. Without achieving energy security, it is hard for countries to maintain their economic and national security in the region.



1.4. Energy Security

Energy security is a complex paradigm as it varies from country to country. It brings together a variety of economic, geological, geopolitical, institutional, and ecological factors. As for energy exporting countries, energy security is the security of demand; thus, that is not an issue due to the continuous increase in global population. However, energy security for energy-importing nations is the security of energy supply at affordable prices without compromising their national security. Further, energy security can be evaluated using 5As'.

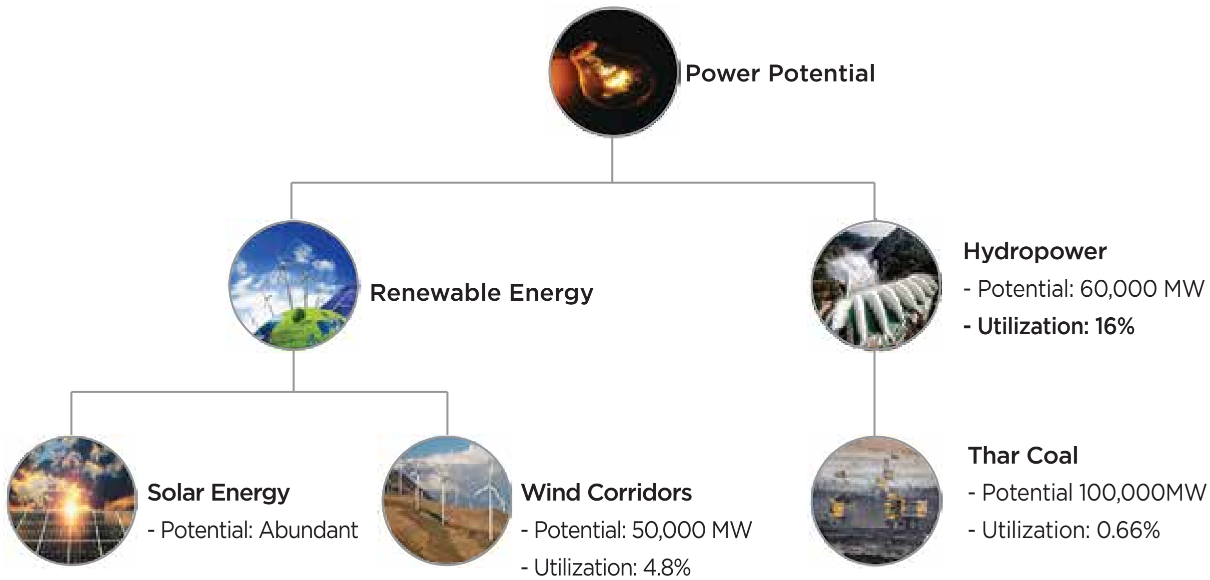
Figure 3: Five dimensions to evaluate sustainable energy security profile



1.5. Power Potential

Pakistan can improve its position on the energy security scale by improving its position on the five above dimensions. Luckily, Pakistan has a geological advantage as it can opt for solar, wind, coal, and hydel energy sources to increase its self-sufficiency. According to Pakistan Economic Survey 2022, the country has immense potential for wind, hydropower, and coal which can meet Pakistan's power demand for many years (figure 4 depicts the same).

Figure 4: Power potential of different energy sources in Pakistan



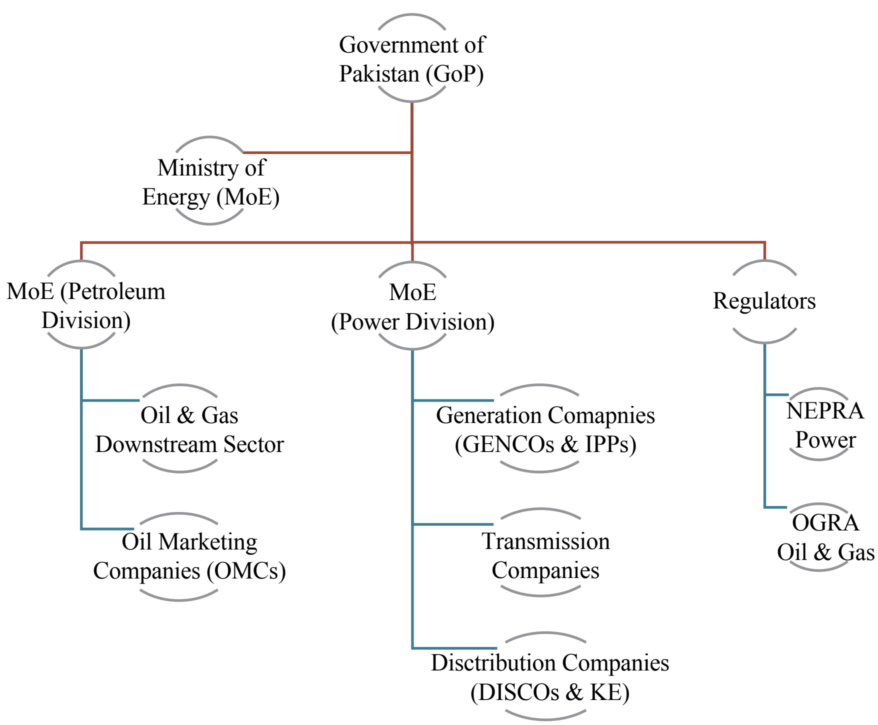
Source: (Pakistan Economic Survey, 2021-22)

2 Overview of Energy Sector

2.1. Regulatory Structure of Energy Sector

The country should have a robust regulatory structure and policy framework to develop a sustainable energy sector. In general, a regulatory and legal framework is required to regulate, expand, and secure the supply of oil, gas, coal, and renewable commodities. Pakistan regulates the energy sector through its designated ministry established in the year 2017. The Ministry of Energy (MoE) is further divided into two divisions: the power division and the petroleum division. The power division is responsible for the development of the power sector in the country whereas the petroleum division looks after the oil and gas sector. In addition to this, National Electric Power Regulatory Authority (NEPRA) and Oil & Gas Regulatory Authority (OGRA) are two separate regulators for the power and oil & gas sectors respectively (see figure 5).

Figure 5: Governance structure of energy sector



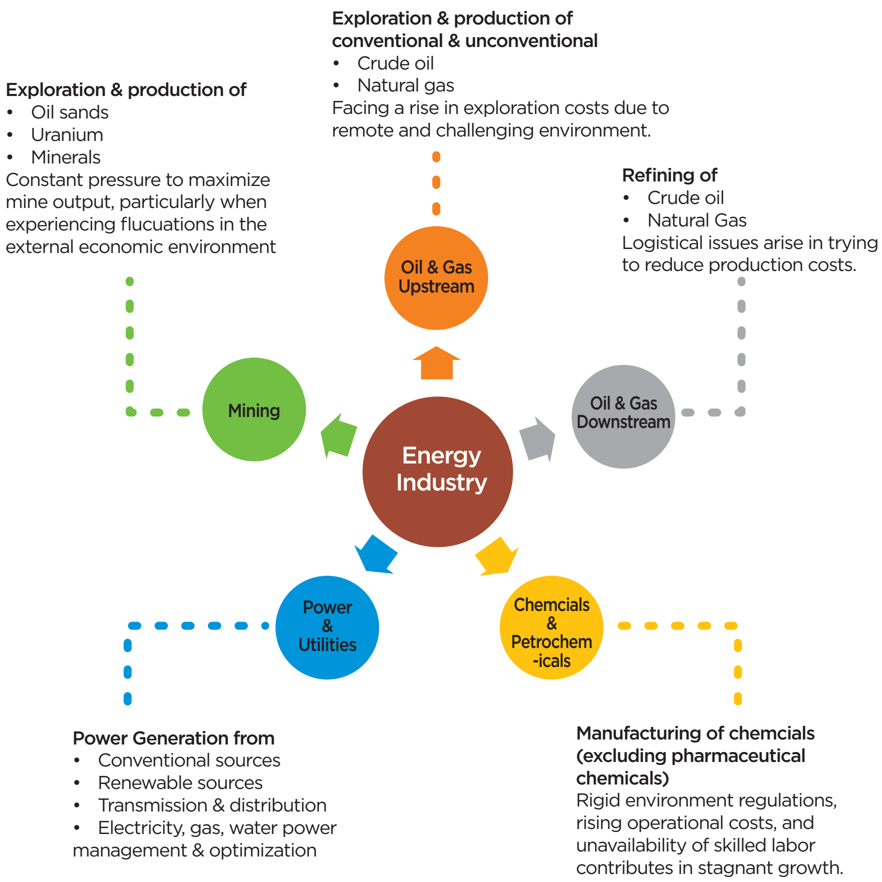
Source: Author

Regardless of the sector's significance and importance in the economic prosperity and well-being of a nation, the energy sector faces policy disconnect. Today, even after 75 years of independence country does not possess an "Energy Policy" to synchronize various policies of sub-sectors within the energy sector. In addition, the country does not have an "Integrated Energy Plan" or "Energy Security Policy" to secure an uninterrupted, and sustainable energy supply at affordable prices.

2.2. Energy Supply Chain

The energy demand is at an unwavering high. With rapid changes in the industry, expectations around efficiency have amplified tremendously. Some of the greatest challenges in the energy industry lie in supply chain management. The energy sector is heavily reliant on local and foreign investors' willingness to invest in the oil and gas upstream sector, mining, power & utilities, chemical & petrochemicals, and oil & gas downstream sector. The oil & gas upstream sector is most crucial for oil-importing countries such as Pakistan as it will determine the quantum of oil & gas imports. Figure 6 depicts the issues attached to all sub-sectors of the energy industry.

Figure 6: Energy supply chain

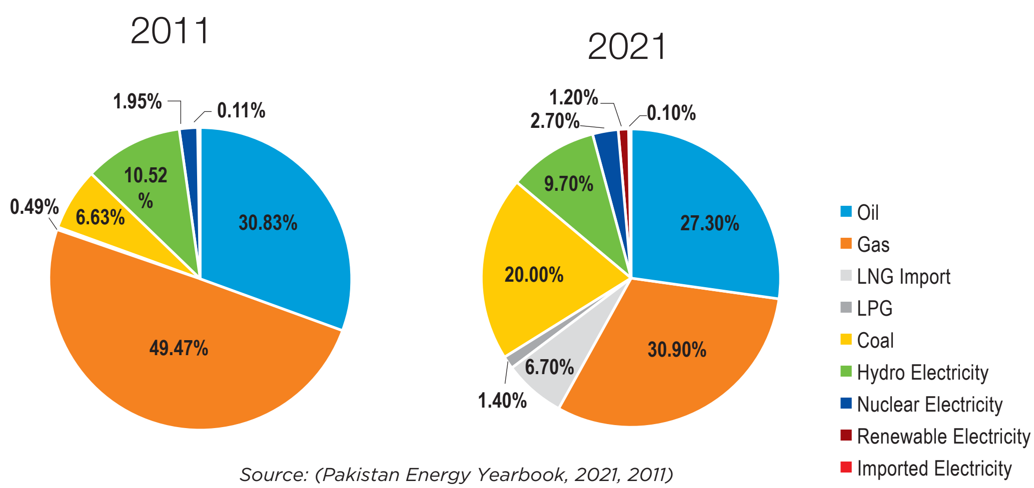


Source: Author

2.3. Primary Energy Supply Mix

The total primary energy supply mix is composed of oil, gas, LNG import, LPG, coal, hydroelectricity, nuclear electricity, renewable electricity, and imported electricity. In 2021 total primary energy supplies stand at 82.6 mmtoe, an increase of 2% from 80.6 mmtoe in the year 2020. In FY 2011, the energy mix was composed of 49.47% natural gas, and 30.83% oil, followed by 6.63% coal. In FY 2021, the share of gas has reduced from 49.47% to 30.90%, the share of coal has increased from 6.63% to 20.00%, and LNG import which accounts for 6.70% was not part of the energy supply mix in FY 2011.

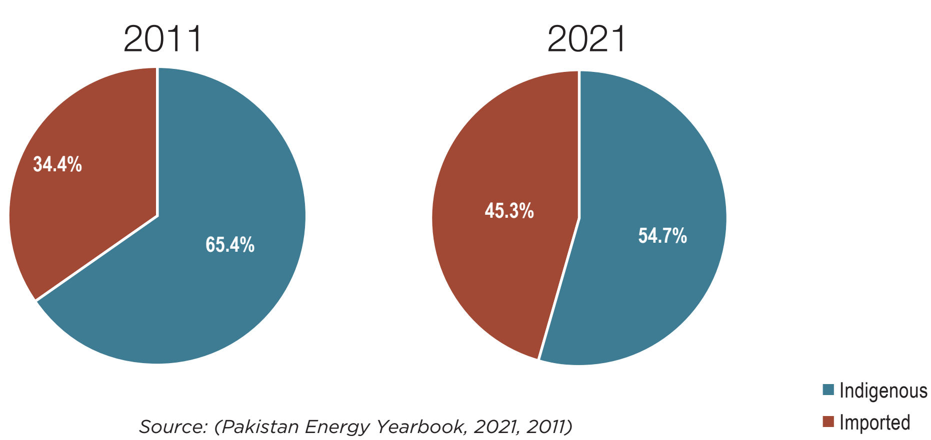
Figure 7: Primary energy supply mix



Source: (Pakistan Energy Yearbook, 2021, 2011)

The energy supply mix suggests that the reliance on fossil energy has significantly increased in 2021 as compared to 2011. In FY 2011, the share of indigenous resources in total supply stand at 65.4% which have reduced to 54.7% in 2021. As Pakistan is a fossil energy import country this significant raise has resulted in higher energy import bills.

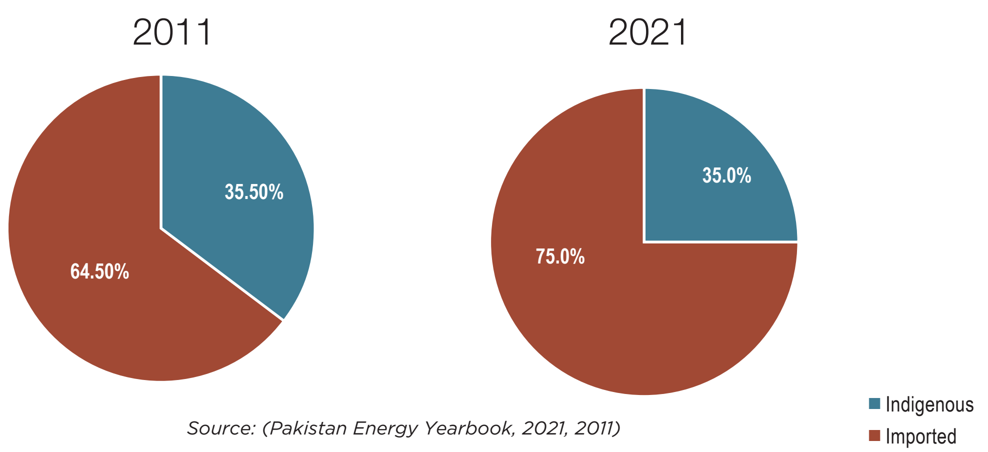
Figure 8: Primary energy supply share



Source: (Pakistan Energy Yearbook, 2021, 2011)

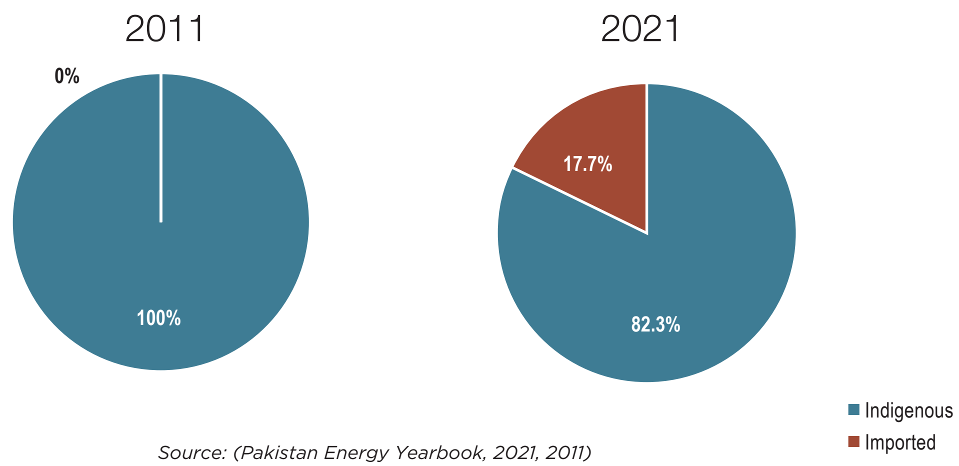
The increase in imports over the years is mainly caused by coal and gas. The imports of coal have increased from 64.5% to 75% and imports of gas have increased from 0% to 17.7% in 2021. Whereas, a little decrease is observed in oil as compared to 2011 but still imported oil accounts for 83.7% of total oil supplies. The surge in imported energy exposes the country to geopolitical threats along with economic dependency on other countries. Apart from geopolitical threat, higher imports result in a humongous import bill and widen the country's current account deficit which is not sustainable in the long run. As discussed earlier, Pakistan possesses coal reserves in abundance and they are enough to meet the demand for many decades to come.

Figure 9: Primary coal supplies



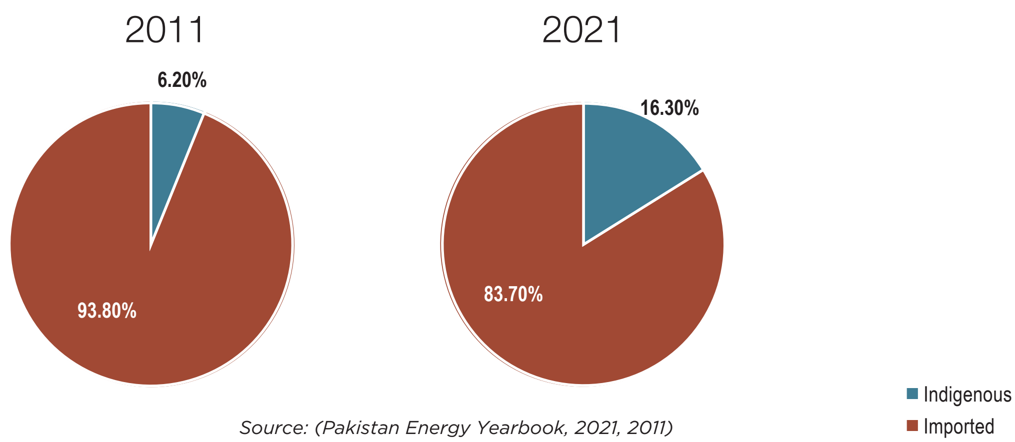
Source: (Pakistan Energy Yearbook, 2021, 2011)

Figure 10: Primary gas supplies



Source: (Pakistan Energy Yearbook, 2021, 2011)

Figure 11: Primary oil supplies

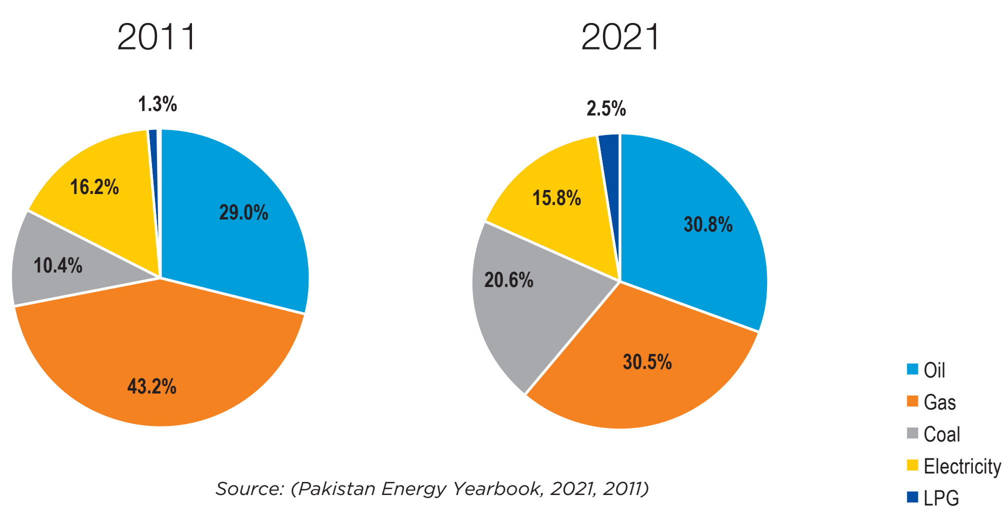


Source: (Pakistan Energy Yearbook, 2021, 2011)

2.4. Primary Energy Consumption Mix

The total energy consumption mix of Pakistan is composed of oil, gas, coal, electricity, and LPG. In FY 2011, the share of oil, gas, coal, electricity, and LPG in total consumption was 29%, 43.2%, 10.4%, 16.2%, and 1.3% respectively. Whereas in 2021 the share of oil, gas, coal, electricity, and LPG is 30.8%, 30.5%, 20.6%, 15.8%, and 2.3% respectively. Over the last 11 years, the share of natural gas reduced, and such reduction is filled by coal; thus, increase in imported energy. In addition to this, the share of electricity has reduced from 16.2% to 15.8% in FY 2021. Electrification of the economy is considered vital for economic growth, the consistent consumption pattern depicts very stagnant electricity consumption in industrial and commercial sectors.

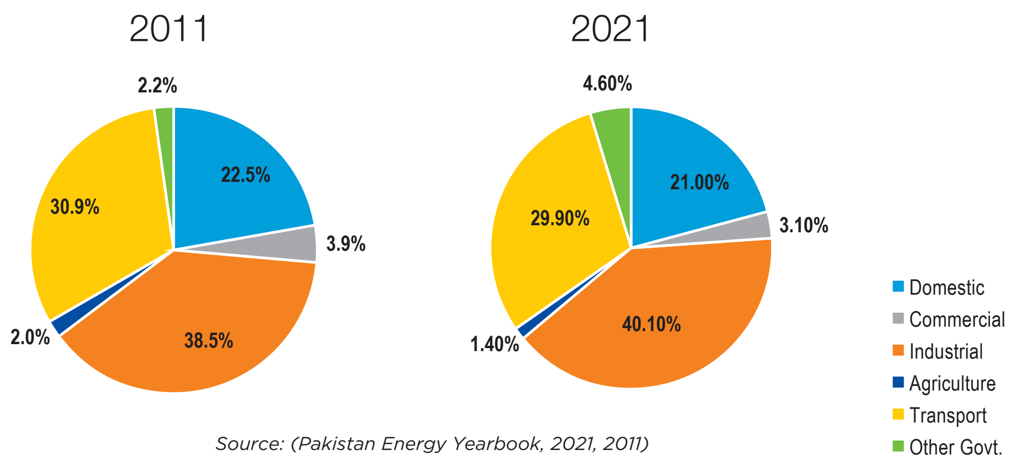
Figure 12: Primary energy consumption mix source-wise



Source: (Pakistan Energy Yearbook, 2021, 2011)

The sector-wise energy consumption can be categorized into domestic, commercial, industrial, agriculture, transport, and other government. The industrial sector has the largest share of total consumption followed by the transport and domestic sectors. In comparison to 2011, a small increase is observed in industrial consumption but not significant. Industrial energy consumption is productive for the economy, as compared to transport and domestic sectors. These two sectors account for almost 50 percent of total consumption.

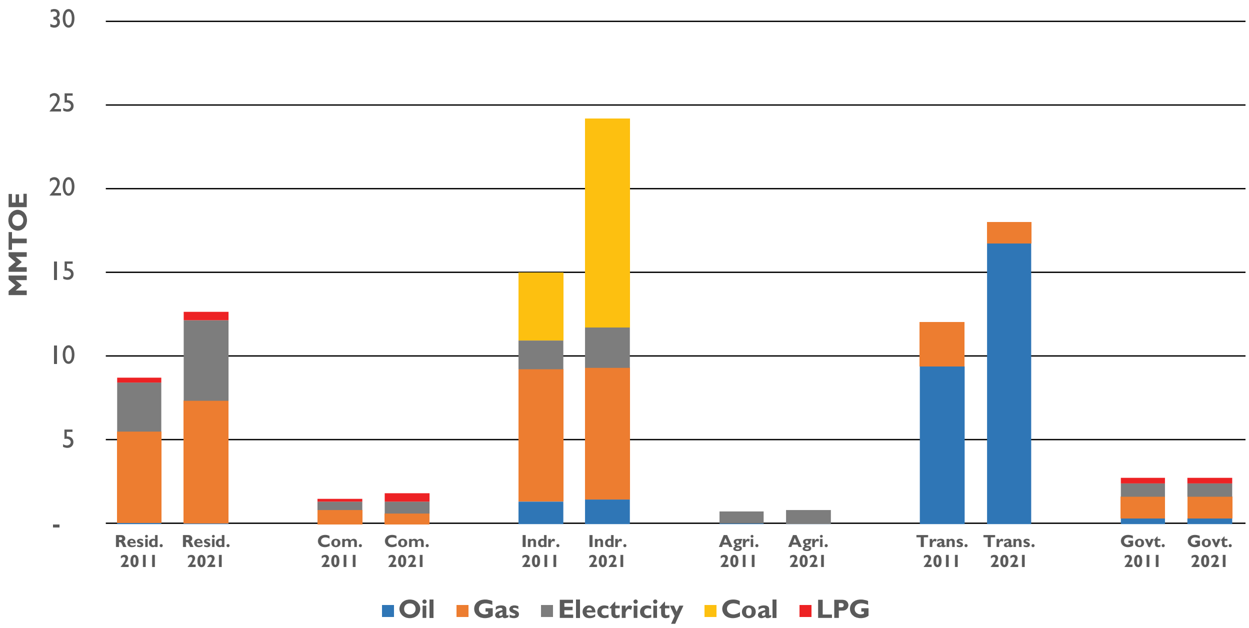
Figure 13: Primary energy consumption mix sector-wise



Source: (Pakistan Energy Yearbook, 2021, 2011)

Furthermore, the energy consumption within the sector shows an unsustainable consumption mix for consistent economic growth. As provided, the residential (domestic) sector has the largest share in electricity consumption, almost 50 percent of electricity consumption is in the non-productive sector. The industry has a small share in electricity consumption. The industrial sector has the largest share in gas consumption but the residential sector has a significant share in gas consumption as well. Whereas the transport sector overwhelmingly dominates oil consumption and coal is consumed by the industrial sector. It is agreeable that the current energy consumption pattern is not sustainable and there is a need to rationalize energy consumption and increase the share of energy consumption in productive sectors. As oil and coal are majorly imported to meet the demand, the utilization of coal and rationalization of oil consumption in the transport sector can help in reducing the country's dependency on other countries.

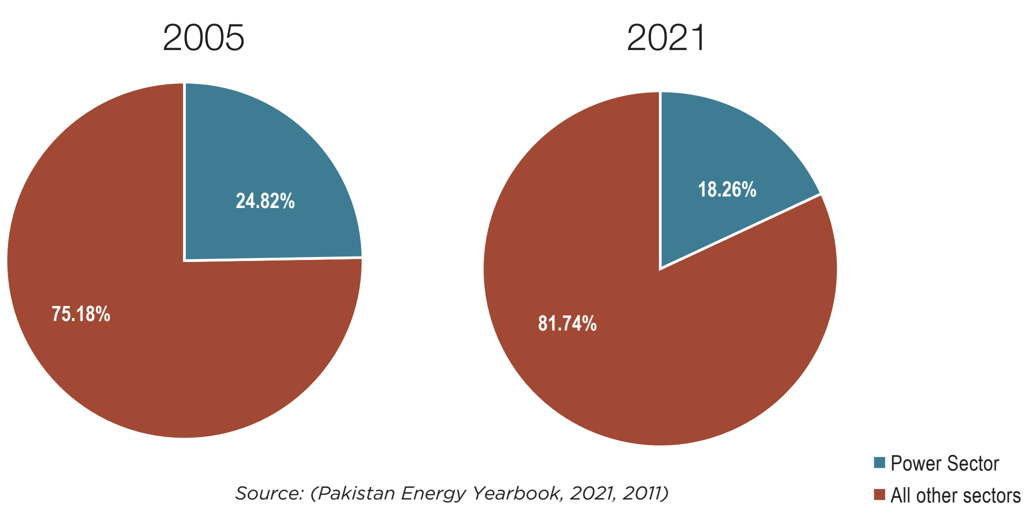
Figure 14: Primary energy consumption by sector & fuel



Source: (Pakistan Energy Yearbook, 2021, 2011)

Among total energy supplies, a substantial amount is used to produce electricity. In Pakistan electricity is produced from fossil & non-fossil energy sources. Fossil energy is produced from oil, furnace oil, coal, and gas. The power policy of 1992 enabled fossil fuel-based Independent Power Plants (IPPs) and since then the power sector is dominated by fossil-based power plants and more than 50 percent of total electricity is still produced by fossil resources. In FY 2005, 24.82% of total supplies were used to produce electricity and that share has reduced to 18.26% of total supplies.

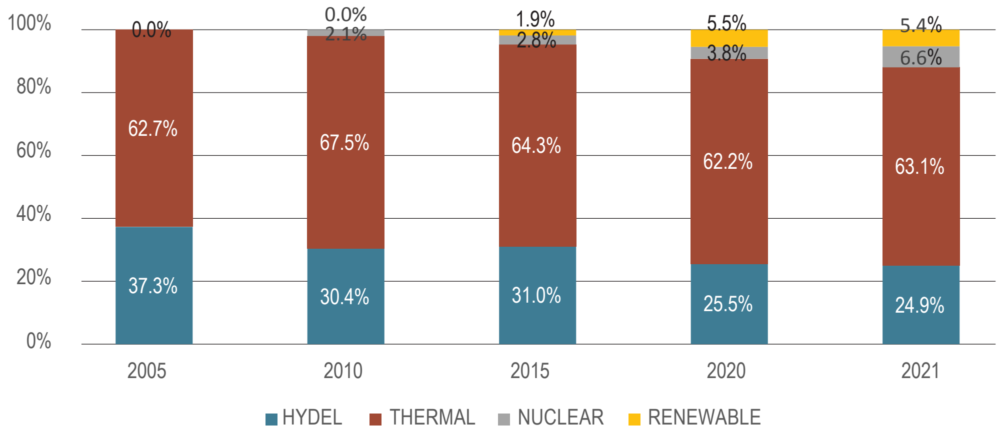
Figure 15: Fossil fuel used in Thermal Power Generation



Source: (Pakistan Energy Yearbook, 2021, 2011)

In FY 2005, 37.31% of the total installed capacity in MW was Hydel based and the remaining was fossil fuel-based. Over the past 16 years, the share of fossil fuel-based installed capacity still dominates all other categories whereas the share of hydel has squeezed to 24.93% and decrease is substituted by 6.57% of nuclear-based, and 5.40% of renewable-based installed capacity in MW.

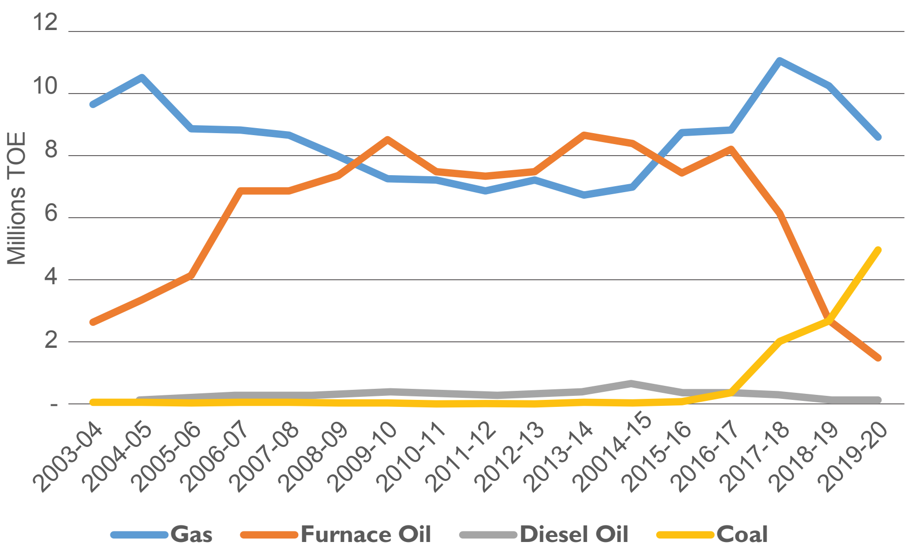
Figure 16: Power generation installed capacity in MW



Source: (State of Industry Report, 2021)

In the early 2000s, the country embraced furnace oil-based electricity generation and it took a decade to realize that Pakistan is not resilient to higher imports. It was in 2016 when patterns of fuel consumption in thermal power generation started changing. With decreasing natural gas reserves and the country's inability to pay for imported furnace oil, local fossil resources are the right option as same can be seen in Figure 11. Pakistan has enough coal reserves to fuel its engine for decades to come but the country imports almost 75 percent of total coal consumption. Thus, Pakistan has just started moving from one imported fuel to another imported fuel; import dependency remains the same.

Figure 17: Fuel consumption for Thermal Power Generation in TOE



Source: (State of Industry Report, 2021)

3 Pakistan's Sustainable Energy Security (PSES) Index

At present, Pakistan is entangled in energy crises and climate change issues. On one side country itself is highly vulnerable to climate change externalities and on the other side, Pakistan possesses significant challenges of disturbance in the supply of energy, unaffordable energy prices, depletion of indigenous resources, lack of investment, and unintegrated energy sector policies. Energy system security and sustainable development are at risk. Therefore, it is necessary to build an energy security index to evaluate the energy security position of Pakistan. The Energy Sustainability Index proposed by World Energy Council (WEC) focuses on energy sustainability and energy security, but no indicator system has been aimed at the evaluation of Pakistan's Sustainable Energy Security. Therefore, following the definition of Sustainable Energy Security proposed by Narula (2015) (Narula, 2015), five dimensions (accessibility, availability, affordability, develop-ability, and acceptability) are utilized to develop Pakistan's Energy Security Index. These all dimensions are combined with indicators used by WEC while fully considering Pakistan's actual and development plans, Pakistan's Sustainable Energy Security Index System is established.

In selecting indicators, full reflection had been given to national planning indicators, such as carbon emission intensity, energy intensity, non-fossil energy consumption shares, etc. In the PSES index (including ten indicators: industrial sector, gross domestic product (GDP) per capita, total primary energy consumption/ total primary energy production (TPEC/TPEP), energy affordability, population with access to electricity, emission intensity, energy intensity, CO2 emissions per capita, TPEP per capita, energy self-sufficiency ratio) developed by WEC are used. Given the above discussion, and for being systematic, objective, maneuverable, scientific, and utilizing the availability of data, 15 indicators are advanced to frame the PSES index, as shown in Table 2.

Table 1: Framework for Pakistan's sustainable energy security (PSES) index

Dimension	Indicator	Equation (per year)	Effect
Availability (A1)	TPEP per capita (A11)	TPEP / Average population	Positive
	Energyreserve-to-production ratio (A12)	A weighted average of reserve-to-production ratio of fossil energy	Positive
	Energy self-sufficiency ratio (A13)	A weighted average of the self-sufficiency ratio of every kind of energy	Positive
Accessibility (A2)	Share of investment in fixed assets of energy (A21)	Investment in fixed assets of energy industry/Pakistan's total investment in fixed assets	Positive
	Crude oil Market Concentration Risk (A22)	COMCR	Negative
	Oil Market Liquidity (A23)	World oil exports/Pakistan's oil imports	Positive
Affordability (A3)	Domestic Fuel price fluctuation ratio (A31)	Fluctuation ratio of domestic retail price index of fuel goods	Negative
	Crude oil price fluctuation ratio (A32)	Average crude oil price fluctuation ratio	Negative
	GDP per capita (A33)	GDP/Average population	Positive
Acceptability (A4)	Share of non-fossil energy (A41)	Non-fossil energy consumption/TPEC	Positive
	Energy intensity (A42)	TPEC/GDP	Negative
	Carbon emission intensity (A43)	CO2 emissions/GDP	Negative
Develop-ability (A5)	TPEC per capita (A51)	TPEC / Average population	Negative
	Carbon emission per unit energy consumption (A52)	CO2 emissions/TPEC	Negative
	Energy diversification index (A53)	SWI	Positive

3.1. Availability

Availability reflects the prospects of local energy supply geographically. The country's indigenous ability to meet its energy requirements is critical as it affects sustainable energy supply and plays a significant role in ensuring sustainable energy security.

A_{11}: TPEP per capita

Total primary energy production per capita is the positive indicator, it represents the domestic supply capacity. The data for TPEP is taken from the Pakistan Energy Yearbook published by the Hydrocarbon Development Institute of Pakistan (HDIP). The data for the total population is taken from the Pakistan Bureau of Statistics (PBS).

A_{12}: Energy reserve-to-production ratio

The energy reserve-to-production ratio reflects the availability of local energy resources over time. It is calculated through weighted averages of the production-to-reserve ratio of different varieties of energy commodities, such as oil, coal, and natural gas. The weight value for each commodity is the corresponding share of that commodity in total energy supplies. The data on energy reserves and total energy supplies are taken from Pakistan Energy Yearbook.

A_{13}: Energy self-sufficiency ratio

An adequate energy supply contributes to the sustainable and balanced development of the country; thus energy self-sufficiency ratio is a positive indicator. The self-sufficiency ratio is the weightage average of self-sufficiency ratios of each commodity, the weight value is the commodities share in the total energy supply.

3.2. Accessibility

The geopolitical aspects and the transport channel play an essential role in the possibilities of energy supply. Countries' reach to international energy markets and domestic energy infrastructure is crucial in ensuring a sustainable energy supply. Thus the availability of adequate infrastructure and energy-importing countries' economic and political conditions are considered.

A_{21}: Share of investment in fixed assets of energy

It represents the share of investment in fixed assets of the energy sector in total fixed investments in the country. This is a positive indicator as the investment in fixed assets significantly improves the infrastructure, production capacity, and energy conservation rate. Which helps in ensuring an adequate energy supply. The investment data is taken from the State Bank of Pakistan (SBP).

A_{22}: Crude Oil Market Concentration Risk

The market liquidity and oil market concentration risk reflect the geopolitical risk for a country. Crude oil is Pakistan's major energy imported commodity; thus, to reflect the influence of geopolitics on energy security this paper takes the Crude oil market concentration ratio (COMCR) and Oil market liquidity (OML) as two parameters.

$$COMCR = \sum_{i=1}^{N} ri * pi^2$$

Where pi^2 is i's refined oil import share in Pakistan's total crude oil supply and ri represents the political risk coefficient of a crude oil importing countries. The top six countries of Pakistan's crude oil imports are included. The political risk coefficient adopts the methodology published by the International Energy Agency (IEA), which is the normalized weighted average of the Absence of Violence/Terrorism index, political stability, and the Regulatory Quality Index published by the World Bank (see Tables A1 and A2 in the appendix). COMCR is a negative indicator, as a high score indicates high energy security risk. The refined oil import data used in this indicator is taken from Pakistan Energy Yearbook.

A_{23}: Oil Market Liquidity

OML is a positive indicator as market liquidity reduces the risk of market concentration. Pakistan's oil import data is taken from Pakistan Energy Yearbook and the world's oil export data is extracted from "The BP Statistical Review of World Energy".

3.3. Affordability

Affordability is the uninterrupted and adequate energy supply at reasonable prices, which is the primary meaning of energy security. The personal paying ability of the nation and fuel prices locally and abroad have a significant impact on energy affordability.

A_{31}: Domestic fuel price fluctuation ratio

This reflects the price stability of domestic energy prices; the higher the fluctuation ratio, the lower the price stability in the country. This ratio is calculated by the retail price index of fuel commodities. The domestic fuel price fluctuation ratio shares a negative relation with energy security. The data for domestic prices from 2011 to 2021 are taken from Pakistan State Oil (PSO) Company Limited.

A_{32}: Crude oil price fluctuation ratio

The energy security and oil price fluctuation ratio have a negative correlation, which is a negative indicator. The crude oil price fluctuation ratio is the percentage change in the average value of Brent, Dubai, and West Texas Intermediate crude oil prices. The crude oil prices are taken from “BP Statistical Review of World Energy”.

A^{33}: GDP per capita

GDP per capita measures the living standard across countries and it is defined as individuals paying ability. The high per capita income shows strong resistance toward the negative impact of high energy prices. The GDP per capita data is taken from SBP.

3.4. Acceptability

It reflects the impact of energy production and utilization on the environment and economy. With the increase in global temperature, and climate change threat people are paying more attention to the environment. The economies need to shift from high-carbon to low-carbon energy sources and from low-energy efficiency to high-energy efficiency structures.

A_{41}: Share of non-fossil energy in consumption

It is the ratio of non-fossil energy consumption to TPEC. The non-fossil energy infrastructure contributes to energy security by enhancing supply capacity, improving safety, and sustainable environment. The non-fossil energy consumption data is taken from the State of Industry Report.

A_{42}: Energy intensity

Energy intensity is the ratio of TPEC to GDP and this indicator is widely used in the evaluation of energy security. Energy intensity is a negative indicator as the rise in energy intensity is considered a decrease in energy efficiency hurts energy security.

A_{43}: Carbon emission intensity

The Paris Agreement is legal binding to develop a low-carbon economy. Carbon emission intensity reflects the ratio of CO2 emission to GDP, thus, a decline in carbon emission intensity improves the energy security performance. For our analysis, CO2 emissions are considered to be entirely caused by the energy sector. The data on CO2 emissions is taken from "BP Statistical Review of World Energy".

3.5. Develop-ability

It reflects the development of sustainable energy system capacity in optimized, low-carbon, and clean mode. If a system is performing at optimized, and clean mode it is considered as most sustainable energy security.

A_{51}: Total Primary Energy Consumption (TPEC) per capita

The total primary energy consumption per capita is used to reflect individual energy consumption and it is considered a negative indicator. A high TPEC indicates inefficient infrastructure, thus high TPEC will increase the risk to energy security.

A_{52}: Carbon emission per unit energy consumption

It is the ratio of CO2 emissions to TPEC. This ratio adopts the relationship between carbon emission and energy infrastructure.

A_{53}: Energy diversification index

The Shannon-Weiner Index (SWI) is used to measure energy consumption diversification:

$$SWI = -\sum_{j=1}^{m} \beta(j)\ \ln\beta(j)$$

Where β(j) represents the share of oil, coal, natural gas, and electricity consumption in TPEC. Excessive dependence on one energy commodity contributes to energy insecurity and vulnerability; thus, diversification helps in reducing the energy security and vulnerability of a country towards excessive dependence on a single energy commodity.

4 PSES Evaluation Modeling

4.1. Data and Variables

This paper uses energy data, economic data, demographic data, and environmental data from 2011 to 2021. In total fifteen indicators are used in the sustainable energy security index. Total primary energy production, total primary energy consumption, and energy production and consumption of each commodity all are in Tons of Oil Equivalent (TOE). GDP data is real value-based, and the unit is 1000 rupees (SBP, State Bank of Pakistan , 2021). Pakistan's total energy imports and exports are measured in TOE. Crude oil prices taken from "BP Statistical Review of World Energy" are in USD/barrel (BP, 2021). The domestic fuel prices are measured in PKR/Liter (Pakistan State Oil, 2022). Worldwide the CO2 emissions are measured in million tons, for our analysis same unit of measurement is used (BP, 2021). The unit of investment is measured in millions of USD (SBP, The Handbook of Economy , 2021). Whereas population, reserves-to-production ratio, retail prices of fuel commodities, and political risk coefficients are all relative numbers; thus, these values are measured in absolute values (BP, 2021).

The raw values of each indicator are calculated (see Table A3 in the appendix). As some indicators have large standard deviations due to their quantum as compared to others. For dimensional unity, the min-max method is used to normalize the raw values of all indicators. In multiple attribute decision making different methods are used to deal with positive and negative type values to make the indicators play a similar and consistent role during the evaluation process. The min-max method is widely used to normalize all types of indicators to make the evaluation consistent. In Table 2, the normalized values of all indicators all obtained through the normalization process, which is as follows:

(1) Negative-type indicators normalization equation:

$$\mathrm{Aij} = \frac{\max(\mathrm{Aij})-\mathrm{Aij}}{\max(Aij) - \min(Aij)} \quad i = 1,\ldots,5, j=1,2,3, Aij \geq 0$$

(2) Positive-type indicators normalization equation:

$$Aij = \frac{Aij - \max(Aij)}{\max(Aij) - \min(Aij)} \quad i = 1,\ldots,5, j=1,2,3, Aij \geq 0$$

Table 2: Normalized values of all indicators

Year	A_{11}	A_{12}	A_{12}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}	A_{41}	A_{42}	A_{43}	A_{51}	A_{52}	A_{53}
2011	1.0000	0.0258	0.9173	0.5201	0.7050	0.0530	0.1806	0.2921	0.0000	0.3793	0.0000	0.0000	0.8347	0.4140	0.1339
2012	0.8631	0.0199	1.0000	0.3735	0.3672	0.2434	0.2773	0.5825	0.0759	0.3381	0.1478	0.2280	0.8110	0.6533	0.0485
2013	0.7945	0.1125	0.9680	0.4559	0.5403	0.2621	1.0000	0.5992	0.1489	0.3735	0.3795	0.4540	0.8838	0.6461	0.0000
2014	0.7467	1.0000	0.9156	0.0000	0.9666	0.1452	0.7639	0.6579	0.1702	0.6861	0.6244	0.5990	1.0000	0.2760	0.1225
2015	0.7503	0.8938	0.7374	0.4135	0.6078	0.1178	0.5835	1.0000	0.2590	0.5608	0.6844	0.6577	0.8968	0.2614	0.4232
2016	0.4732	0.7414	0.5253	0.5294	0.4038	0.2194	0.6049	0.7330	0.4029	0.4163	0.6487	0.5857	0.2999	0.8283	0.5751
2017	0.4947	0.7323	0.2857	0.2218	0.2442	0.0545	0.2735	0.3884	0.4748	0.0000	0.6381	0.6353	0.0000	1.0000	0.6200
2018	0.4123	0.6916	0.0000	1.0000	0.3541	0.0000	0.1324	0.3143	0.6971	0.0521	0.6169	0.7048	0.1051	0.7141	0.8649
2019	0.2324	0.3435	0.1199	0.5147	0.0000	0.6865	0.2638	0.6805	0.8153	0.4267	0.7832	0.7833	0.2079	0.3596	0.9212
2020	0.0000	0.0338	0.2352	0.4461	0.7499	1.0000	0.5374	0.8828	0.7957	1.0000	1.0000	0.9316	0.5236	0.0000	0.9972
2021	0.1445	0.0000	0.1342	0.3470	1.0000	0.4588	0.0000	0.0000	1.0000	0.6426	0.9924	1.0000	0.0191	0.3714	1.0000

4.2. PSES Evaluation Modeling

In an evaluation of the sustainable energy security index, all indicators within one dimension have a combined weight of 1. As this paper uses five dimensions i.e. availability, accessibility, affordability, acceptability, and develop-ability, these five dimensions have a combined weight of 1. Each indicator is important and plays its role in the establishment of a sustainable energy security index but some indicators are more important than others. The entropy weighting method assigns relative weights to each indicator objectively, this method calculates the difference between the numerical values of all indicators. According to the entropy method, the higher the difference, the larger the weight of that indicator, and vice versa. This method assigns the weights accurately and objectively and has higher reliability in multiple-attribute decision-making than the subjective weighting method. Further, for our analysis "Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)" is used to evaluate, prioritize, and select the best available solution from a set of discrete variables (Mansson, 2014). The TOPSIS technique selects the best available solutions in a limited number of available options and assigns weights measured by the entropy. To determine accurate results, the entropy weight method and the TOPSIS technique are combined to establish the entropy-TOPSIS evaluation method. The detailed methodology is available in appendix.

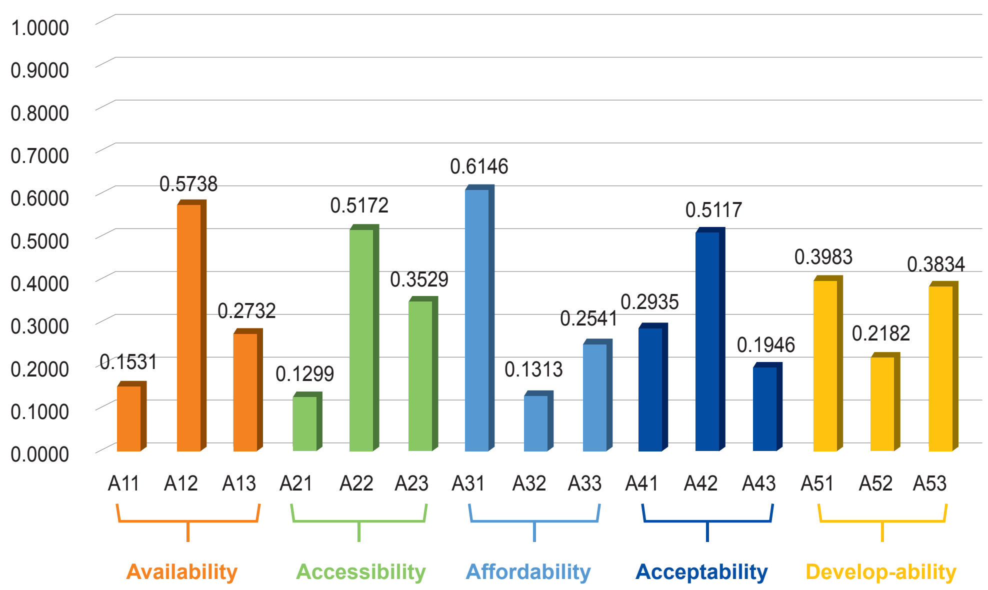
5 Empirical Analysis and Discussion

According to the evaluation model established in section 2, the approach degrees and scores of five dimensions are calculated from the year 2011 to 2021.

5.1. Approach degree of dimensions

The weights of each indicator are obtained using equation (6), and ideal solutions are obtained using equation (9), (see Table A4 in the appendix). Further, the Euclidean distances of each indicator from their respective ideal solutions are calculated using equations (10), and (11). The approach degrees are obtained using the equation (12), see Table 3. Whereas the weights of each dimension are obtained using equation (6), see figure 19.

Figure 18: Weight of each indicator



The weights of each indicator indicate the significance of each indicator within a dimension.

Availability: The reserves-to-production ratio dominates the dimension; this shows the significance of indigenous resources.

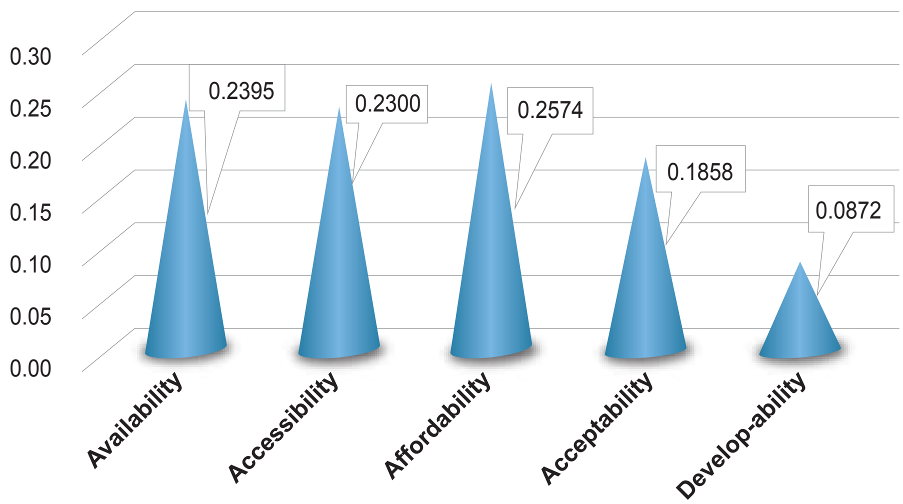
Accessibility: COMCR has the highest weight among all three indicators in the accessibility dimension; thus, it is vital to diversify energy import suppliers.

Affordability: The domestic fuel price fluctuation ratio is significant; this shows the importance of stable fossil fuel retail prices.

Acceptability: Energy intensity dominates the dimension; this indicates the significance of energy used to produce 1 USD in GDP.

Develop-ability: TPEC per capita and SWI are equally important; this shows the significance of diversified commodities and energy consumed by a citizen.

Figure 19: Weight of each dimension



The weights of affordability, availability, and accessibility are relatively large; which indicates that reasonable energy and energy supply security has a great significance on Pakistan's sustainable energy security.

Table 3: Approach degrees of dimensions

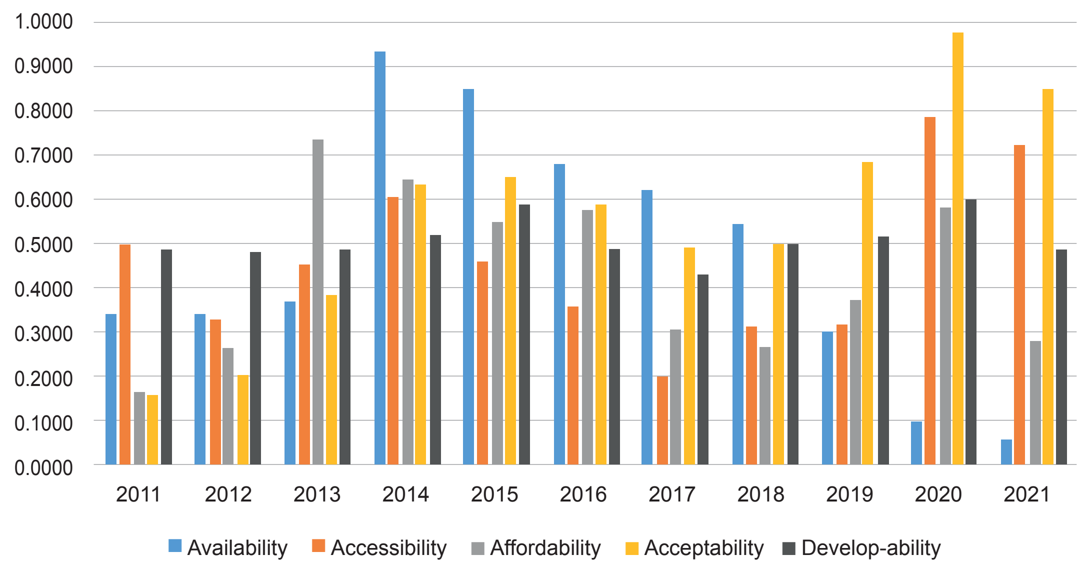
Year	Availability	Accessibility	Affordability	Acceptability	Develop-ability
2011	0.3445	0.4991	0.1704	0.1618	0.4904
2012	0.3505	0.3322	0.2709	0.2093	0.4819
2013	0.3688	0.4550	0.7361	0.3857	0.4905
2014	0.9338	0.6045	0.6484	0.6352	0.5218
2015	0.8471	0.4589	0.5494	0.6525	0.5889
2016	0.6811	0.3581	0.5794	0.5873	0.4874
2017	0.6253	0.2000	0.3106	0.4963	0.4321
2018	0.5434	0.3160	0.2673	0.4995	0.5022
2019	0.3051	0.3206	0.3782	0.6844	0.5173
020	0.0988	0.7873	0.5827	0.9789	0.6010
2021	0.0632	0.7224	0.2879	0.8457	0.4863

5.2. Dimensional Analysis

According to the evaluation model, the values of each dimension from 2011 to 2021 were calculated, the results are provided in figure 20.

Availability: Taking the year 2014 as a demarcation line for availability, fluctuation in dimension can be explained in two stages from 2011 to 2021. From 2011 to 2014 energy availability improved mainly due to increase in total fossil fuel reserves on account of Thar coal. However, from 2014 to 2021, it decreased continuously due to increase in use of local production of all fossil fuel commodities and subsequent reduction in reserves. Hence, it is important to possess enough fossil fuel reserves to meet increasing energy demand without compromising the usage life of reserves.

Figure 20: Approach degrees of dimensions



Source: Author

Accessibility: During the evaluation period, energy accessibility presented fluctuated trend. External energy accessibility is affected by geopolitics, and geopolitical risks. The improvement in energy accessibility is mainly due to lower market concentration risk and higher oil market liquidity. Whereas, the decline in energy accessibility from 2014 to 2017 was result of higher market concentration risk and lower oil market liquidity. On the whole, Pakistan's energy accessibility has shown a significant fluctuations, to which special attention needs to be paid.

Affordability: The volatility of affordability is high, mainly because the fluctuations and trend in domestic fuel price and international crude oil prices cannot be determined. The affordability score was only 0.2673 in 2018; that was the lowest level during the study period, which was on account of increased domestic fuel price and international crude oil price compared with 2016. During the period 2018-2020, the affordability improved significantly, as the fluctuation in energy price was small, and GDP per capita showed an increase. Further, in 2021, affordability declined sharply due to increase in domestic fuel price and international crude oil price post-COVID. The performance of affordability is showing sharp fluctuations as the personal paying ability has not increased significantly and country's ability to deal with the risk of energy price fluctuations has not been improved; hence, there is need to pay attention to improve country's ability to digest energy price fluctuations.

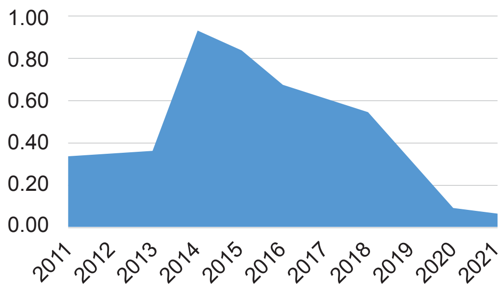
Acceptability: Energy acceptability generally shows an upward trend. In Pakistan's case energy accessibility has improved on account of positive change in share of non-fossil energy in energy mix, lower energy intensity, and reduced carbon emission intensity. However, during 2015-2018, energy accessibility reduced due to lower share of non-fossil energy in energy mix compared to same in 2017 and higher energy intensity.

Develop-ability: During the evaluation period, the primary energy consumption per capita shown fluctuations, carbon emission per unit of energy consumption increased during 2011-2020, and energy diversification index improved consistently. However, there was a drop in 2017. The main reason is that the primary energy consumption per capita increased in 2017 along with rise in carbon emission per unit energy consumption. The harmonious development of energy, the economy, the environment should be the main objective of Pakistan's energy security.

The reasons for fluctuations in each dimension are presented graphically in figure 21.

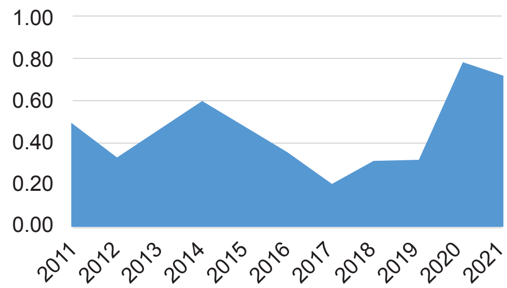
Figure 21: Results of five dimensions

Availability



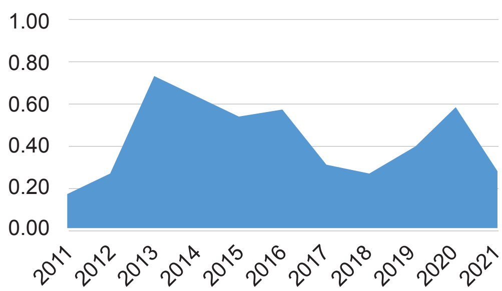
Indicator		A11	A12	A13
Weight		0.1531	0.5738	0.2732
Stage I	2011 - 2013	Red	Green	Green
Stage II	2013 - 2014	Red	Green	Red
Stage III	2014 - 2021	Red	Red	Red

Accessibility



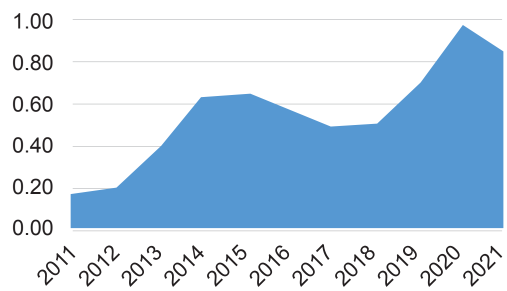
Indicator		A11	A12	A13
Weight		0.1531	0.5738	0.2732
Stage I	2011 - 2015	Red	Green	Green
Stage II	2015 - 2017	Green	Red	Red
Stage III	2017 - 2020	Red	Green	Green

Affordability



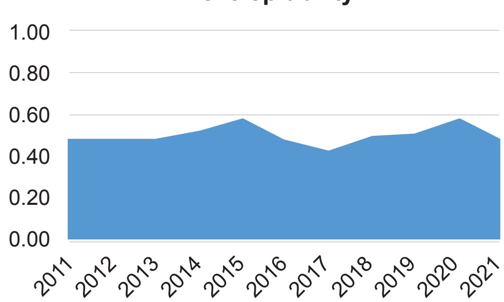
Indicator		A11	A12	A13
Weight		0.6146	0.1313	0.2541
Stage I	2011 - 2013	Green	Red	Green
Stage II	2013 - 2016	Green	Red	Green
Stage III	2016 - 2018	Red	Red	Green
Stage IV	2018 - 2020	Green	Green	Red
Stage V	2020 - 2021	Red	Red	Green

Acceptability



Indicator		A11	A12	A13
Weight		0.2936	0.5117	0.1946
Stage I	2011 - 2015	Green	Green	Green
Stage II	2015 - 2017	Red	Red	Green
Stage III	2017 - 2020	Green	Green	Green
Stage IV	2020 - 2021	Red	Red	Green

Develop-ability



Indicator		A11	A12	A13
Weight		0.3983	0.2182	0.3834
Stage I	2011 - 2015	Green	Red	Green
Stage II	2015 - 2017	Red	Red	Green
Stage III	2017 - 2020	Green	Red	Green
Stage IV	2020 - 2021	Red	Green	Green

Red represent decline in indicator

Green represent improvement in indicator

5.3 Current Security Paradigm

1 PSES Level

The new positive and negative ideal solutions are obtained through equation (9). D^+ and D^- reflects the distances between the sample dimension value and the ideal value. The PSES level for every year is calculated using equation (12), see Table 4

Table 4: PSES level during 2011-2021

Year	D^+	D^-	Level
2011	0.2621	0.0964	0.2690
2012	0.2557	0.0801	0.2386
2013	0.1908	0.1782	0.4830
2014	0.0800	0.2740	0.7739
015	0.1101	0.2384	0.6840
2016	0.1429	0.2015	0.5850
2017	0.2097	0.1526	0.4213
2018	0.2075	0.1361	0.3961
2019	0.2138	0.1284	0.3751
2020	0.2038	0.2299	0.5301
2021	0.2402	0.1775	0.4250

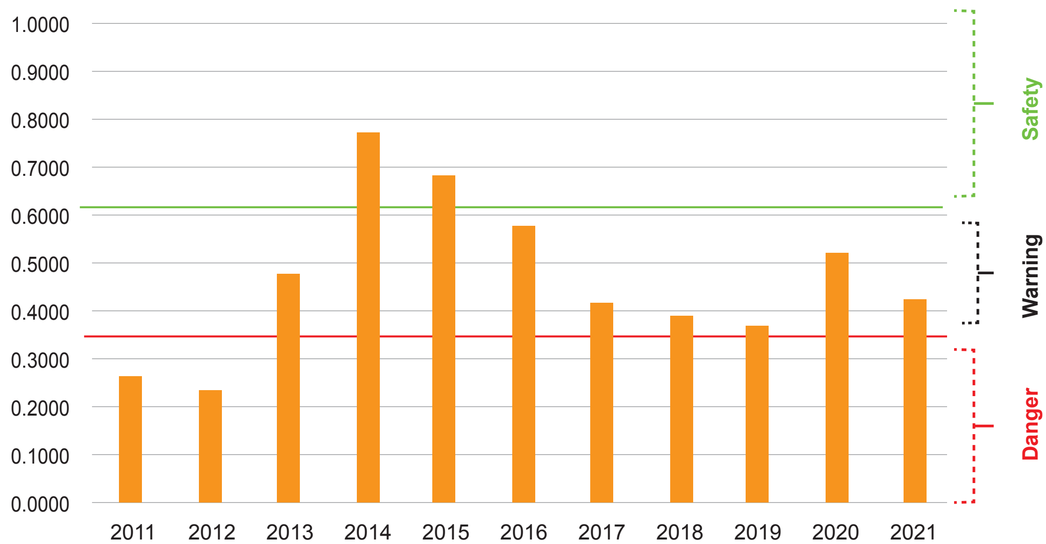
2. PSES Status

In figure 22, the status of Pakistan's security paradigm is shown. The K-means clustering approach[1] is used to classify the security paradigm into three levels; safety, warning, and danger. Two demarcation lines to classify the paradigm into three levels are **0.6112** and **0.3542**. Pakistan's safety zone is above 0.6112 value and the danger zone is below 0.3542. The warning zone is in between two demarcation lines.

Pakistan's energy security status can be explained in two stages, before 2015 and after 2015 as depicted in figure 22. PSES level show's upward trend till 2015 followed by a downward trend. Pakistan's energy security level improved in 2013 as it jumped from a danger state to a warning state. Furthermore, the PSES level shows an improved trend from 2013 to 2016 as it was in a safety state from 2014 to 2015 but followed a consistent decrease till 2019. In the year 2020 energy security improved by 41.3% however, it fell by 19.8% in the year 2021. Thus, Pakistan's sustainable energy security position remains very grim.

[1]K-means clustering is widely used technique, it is used in a pre-specified number of clusters, and the method assigns records to each cluster to find the mutually exclusive cluster of spherical shape based on distance. The value of K is obtained by calculating variance of SES level using different centroids. The elbow point of variance is taken as value for K.

Figure 22: Pakistan's Sustainable Energy Security (SES) status during 2011-2021



Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Level	*Danger*	*Danger*	*Warning*	*Safety*	*Safety*	*Warning*	*Warning*	*Warning*	*Warning*	*Warning*	*Warning*

A continuous decline in the energy security level is a result of ad-hoc policies. In 2017 the government of Pakistan established the ministry of energy. National Power Policy 1994, 1995, and Power Policy 2002 enabled private investment in power generation. Under the 1994 policy, 16 furnace oil and gas-based Independent Power Plants (IPPs) were added to the system and in 2002, further 13 IPPs were added to the system. These all IPPs were promised 10 to 15 percent of IRR with 25-30 years of project life. In addition to this, the government of Pakistan promised to pay all payments in dollar values and fuel supply contracts with a GOP guarantee. The 1994 policy resulted in projects which did not meet the "least cost" generation test because of unsuitable location, excessive reliance on oil and steam turbine technology instead of more efficient combined-cycle plants, and small size. The same mistake was repeated in the Power Policy 2002. The policy encouraged the exploitation of indigenous resources but attracted plants with the same expensive fuel mix. Similarly, in 2013 and later in 2015, despite severe criticism of earlier policies, the new policies came up with more or less the same set of incentives for the generation. The power policies in the 1990s and 2002 have resulted in higher per-unit electricity costs. In addition to this, these power projects were based on imported fuel which increased the country's reliance on imported fuel. However, the Alternate & Renewable Energy Policy 2019 introduced number of small wind turbines, and solar, bagasse power plants in the system; thus, increasing the self-sufficiency of the power sector.

In the years 2011 and 2012 country's energy security was in a danger state as all dimensions were in an alarming position, apart from accessibility, all other four dimensions were below the demarcation line of **0.3542**. The compromised energy security from 2011 to 2012 was mainly due to lower GDP per capita, higher domestic fuel price fluctuations, a small share of non-fossil energy, and higher energy intensity. In 2014 and 2015, the PSES level improved due to the synthetic effect of improvement in availability, accessibility, acceptability, and affordability. Availability has continuously been declining since 2015 due to TPEP per capita, and reserves. The accessibility started declining from 2015 to 2017 followed by an increasing trend. Moreover, affordability declined in 2017 and 2018 followed by improvement in 2019 and 2020, whereas, acceptability showed consistency after 2014 followed by a sharp increase from 2019 to 2020.

PSES level has declined from 2016 to 2019 and reached to 0.3751 due to the combined effect of all five indicators (availability, accessibility, affordability, acceptability, and develop-ability). In 2020, the PSES level improved as a result of the synthetic effect of all indicators except availability. This rise in PSES levels may be attributed to COVID'19.

6 Sensitivity Analysis

Alternate cases were developed to evaluate the energy security paradigm of Pakistan. As part of the analysis, five different scenarios were established to find possible combinations starting from 2011 that could have resulted in better PSES levels and have suggested ways to improve the deteriorating energy security of the country. The five scenarios established are as follows:

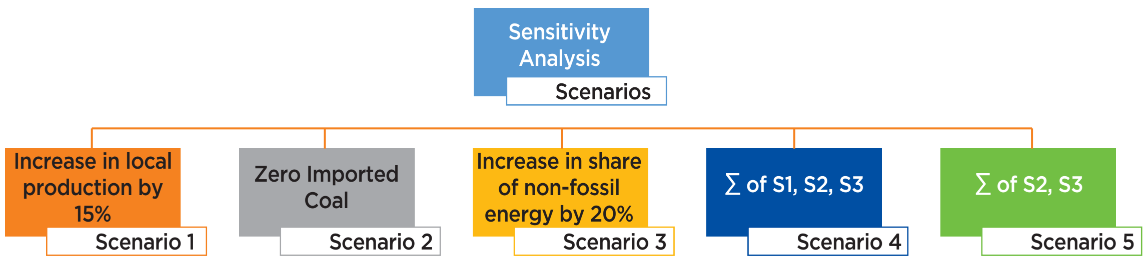
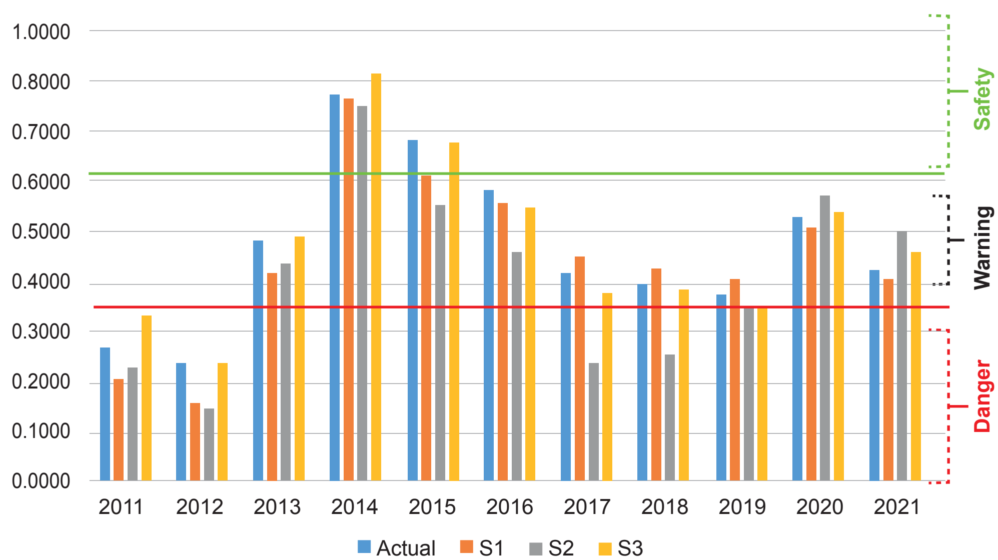


Figure 23: Pakistan's SES Level - Actual, S1, S2, S3

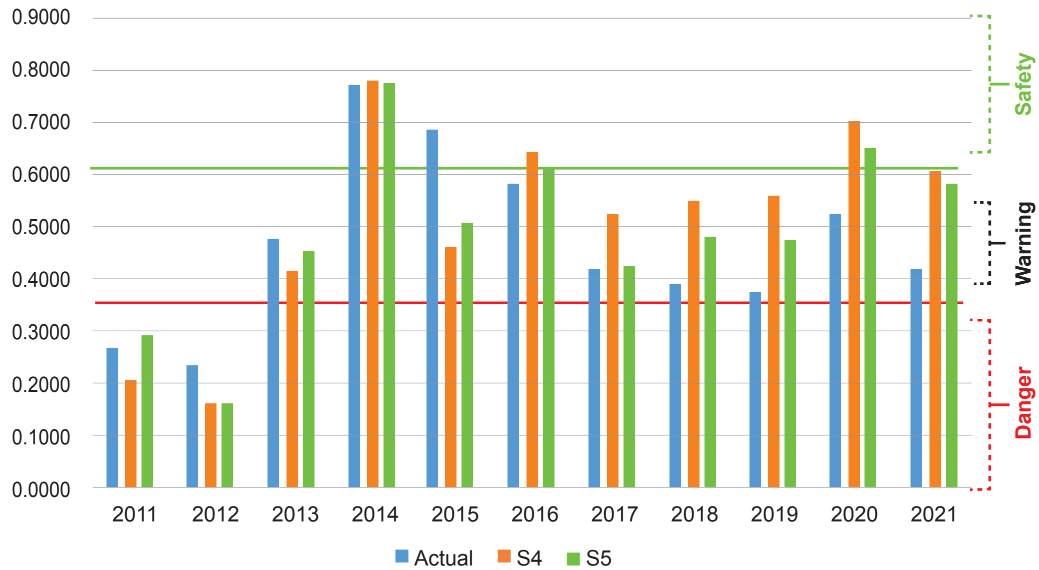


Based on Figure 23, if all three scenarios are implemented separately, energy security does not improve significantly. Till 2016, actual scenario is relatively performing better then S1 , S2 , and S3 . However, from 2017 to 2019, S1 performed better, followed by S2 in 2020 and 2021. It is further observed that if in 2011, indigenous fossil fuel production was increased by 15%, the PSES level would have been more compromised. Meanwhile, if Pakistan banned imported coal and used 100% local coal, the PSES level would have deteriorated further in 2017 and 2018. While an increase in non-fossil energy share by 20% would not have changed the PSES level.

It is apparent from the above discussion that any one of the above three measures might not have improved the country's energy security in isolation. There is a need for a more robust approach to cater to the country's energy security crises which are looking very grim. In this regard, more integrated scenarios are developed and discussed.

Figure 24 compares the current PSES level with S4 and S5 . As can be seen, S4 and S5 perform better than the current PSES levels in 2016 and onwards. Thus, Pakistan's PSES level would have significantly improved if it had increased its indigenous production by 15%, utilized 100% indigenous coal, and increased its share of non-fossil energy by 20% in 2011.

Figure 24: Compares the current PSES Level with S4[5] S5[6]



[2] *S1: Increase in local production of fossil fuels by 15%*
[3] *S2: Zero imported coal is used*
[4] *S3: Increase in share of non-fossil energy by 20%*
[5] *S4: Combination of S1, S2, and S3*
[6] *S5: Combination of S2 and S3*

7 Conclusion

Energy-importing countries are usually vulnerable to geopolitics due to their position in supply chain. In the current era, national and economic security is highly correlated with energy security. These three policies move together and without having a strong level of energy security it is nearly impossible to achieve national security. According to WEC, energy security can be improved through five different channels; availability, accessibility, affordability, acceptability, and develop-ability. As per analysis, affordability, availability, accessibility and acceptability are respectively important for Pakistan to ensure energy security.

The entropy-TOPSIS evaluation model filters six indicators from fifteen indicators which are most significant in ensuring a sustainable energy security level. Such indicators are stable and affordable domestic energy prices, sufficient availability of indigenous resources, geopolitical stability, lower energy intensity, lower primary energy consumption per capita, and diversification of energy suppliers and supplies.

The energy security paradigm of Pakistan can be analyzed in two stages; before 2016 and after 2016. From 2013 to 2016 energy security of the country improved from being in the warning zone to reaching safety zone, due to rise in all five dimensions of energy security. However, since then energy security of the country had deteriorated. After 2016, Pakistan's SES level remains in warning zone, however, it improved by 41.3% in 2020 mainly due to COVID'19. In 2021 as the world moved to normalized life after COVID'19, the PSES level fell by 19.8%. Pakistan's vulnerability to geopolitics, unstable dollar value, and soaring import bills can be attributed to its reliance on imported energy. The increase in reliance on imported energy is mainly caused by Power Policies that enabled private investment in imported fossil energy-based power plants with the promise of having a consistent fuel supply. In addition to this, the soaring petroleum products consumption in the transport sector, non-utilization of local coal reserves, rising domestic energy consumption, lower electricity consumption in industrial and commercial sectors, irrational natural gas prices, absence of coordinated energy policy, weak regulatory structure, political crises, lower local investment in drilling and exploration of indigenous gas and oil reserves, and lower GDP growth has further compromised country's energy security.

To identify possible ways to improve the energy security of the country, a sensitivity analysis approach has been used. Three different scenarios were employed to assess the security profile. In the first scenario, local production of fossil fuels has been increased, the second scenario allows the 100% of local coal use and in the third scenario 50% of electricity production was derived from non-fossil energy. The results indicated that individual implementation of the above scenarios failed to improve the overall energy security profile of the country. Achieving energy security is a complex phenomenon that requires a comprehensive and integrated effort. Furthermore, the above scenarios were combined to quantify the synergized impact on energy profile. The analysis proved that Pakistan should raise its local production, the freeze use of imported coal, and produce at least 50% electricity from non-fossil fuel to achieve energy security

8 Policy Recommendations

This study proposes following policy measures to ensure sustainable energy security:

Fact Track Utilization of Thar Coal

- Thar coal is a game-changing fossil resource of the country. It has potential to meet country's energy demand in decades to come. It is vital to ensure consistent fuel supply to fossil fuel based power plants to ensure uninterrupted electricity supply which leads to economic and social prosperity. Imported coal based power plants should be converted to local coal and other fossil energy based power plants should be gradually substituted with local coal based power plants without compromising country's climate change position. Making use of safer coal-use technologies such as supercritical turbines.

- The Coal to Liquid CTL and Coal to Gas CTG technologies for Thar Coal hold the key to bring Pakistan out of perpetual dependency on imported fuel. Local investment with joint ventures with foreign companies in CTL and CTG technology should be encouraged under Thar coal-based-energy security policy.

The Urgent Requirement for an Integrated Energy Plan

- Current energy crises are result of an unsynchronized energy sector framework which results in isolated power and oil & gas sector policies. An integrated energy plan must be developed to synchronize all policies in the energy sector to achieve self-sufficiency and curtail unnecessary demand/wastage. The Ministry of Energy should be restructured and separate departments should be established for Gas, Petroleum Products, Thar Coal, and Power.

- Separate gas security policy, oil security policy, coal security policy, and power security policy should be devised with stakeholders' input to ensure the availability of each commodity at affordable prices. These four security policies must serve under the energy security policy to reduce reliance on imported energy and ensure an uninterrupted supply of energy.

Indigenization of Power Sector

- Currently, power sector is 58.9% indigenous with 41.1% reliance on imported fuels. As per IGCEP 2021-30 plan, by 2030 power sector will achieve 90.2% self-sufficiency. However, IGCEP 2022-31 plan does not adhere to its earlier commitment, 6% to 7% variation is observed. To realize self-sufficiency, all successive governments should strictly adhere to the IGCEP plan.

Uninterrupted energy supply at affordable prices

- **Rationalization of energy prices**

    - Industrial and commercial consumers are burdened with higher energy prices to subsidize energy prices for residential and agriculture consumers. The cross-subsidization between sectors must be abolished to reduce the unjustified increase in energy costs for industrial and commercial consumers. Real prices will help to curtail excessive consumption by residential consumers and make industrial production globally competitive.

    - The natural gas prices are kept very low making the sector unsustainable in the long-run. To curtail undue rise in demand for gas in residential sector, rationalization of gas prices is required. The Weighted Average Cost of Gas (WACOG) bill must be implemented and to reduce unjustified arbitrage in gas prices among different users. In addition, residential and remote consumers should be encouraged to use gas cylinders.

    - The furnace oil-based power plants should be retired and an audit of efficiency of availability factor of all IPPs is needed to reduce undue capacity charges.

- **Demand management**

    Oil is the largest imported energy commodity and a major part of it is consumed by the transport sector. One way of reducing oil imports is to reduce petroleum product consumption in the transport sector. The following measures can help in reducing oil consumption in transport sector:

    - The local road and EV charging infrastructure must be developed to facilitate the use of EVs across Pakistan. However, the EV charging infrastructure must be developed by using locally made machinery and appliances, as far as viable.

    - Public Transport Projects are a great source of reducing petroleum product consumption in the transport sector. Pakistan can save USD 0.8 to 1 billion in fuel imports if planned BRTs in Karachi are implemented. Thus, public transport projects in the pipeline must be completed on a priority basis and new projects must be devised to discourage the use of personal vehicles in metropolitan cities. In addition, the expansion of public transport is required through BRT, Circular Railway, and Pakistan Railway freight trains.

    - All economic activities must follow energy-saving market timings to smoothen energy consumption until power sector achieves self-sufficiency of 90.2% in 2030 (IGCEP, 2021).
    - Energy conservation measures must be encouraged and monitored through labeling of electric appliances, audit of already constructed buildings, licensing of new

houses and buildings, and retirement of old vehicles. In addition, the National Energy Efficiency and Conservation Authority (NEECA) should work under the mandate of the Ministry of Energy.

Development of competitive energy markets

- The energy sector of Pakistan should gradually move towards competitive markets to reduce the sovereign guarantee burden. The competitive energy markets will enable competitive pricing of energy commodities. The Competitive Trading Bilateral Contract Market (CTBCM) model should be implemented in 2023 as per the NEPRA plan and by 2030 power market may enter into the retail competition.

- A competitive wholesale market should be developed in the Gas sector. SSGCL and SNGPL may supply gas to local gas distribution companies through competitive bidding and such distribution companies should supply gas to end consumers at regulated prices until retail market becomes a feasible option. The local distribution companies' model will help in regulating the infrastructure and reduce UFG losses through rehabilitation of existing distribution networks.

- OMC's margins and IFEM should be deregulated competitively and allow OMCs to price their products.

Emergency stock under oil security policy

- Under oil sector policy all OMCs should be bound to maintain emergency storage reserves of petroleum commodities equivalent to 30 days of weighted average consumption. To ensure emergency stock provision all OMCs should inform relevant regulators of their reserve status at the end of each month. In addition, the regulator should audit OMCs reserves quarterly to ensure availability of emergency reserves.

Investment in exploration and production activities

- Drilling and exploration activities must be encouraged, as the local gas reserves are depleting, therefore substantial efforts are needed to enhance drilling intensities in KPK and Baluchistan provinces as these two provinces are rich in hydrocarbon deposits. According to the Pakistan Energy Year Book, the current drilling intensities for Punjab, Sindh, Baluchistan, and KPK in 2020 were 1.13, 5.23, 0.22, and 0.42 respectively. The lifeline of gas reserves should be increased by exploring new gas reserves, and incentivizing E&P companies to explore unconventional and shale gas sources. There is an urgent need to remove impediments to accelerate natural gas drilling activities in the frontier regions of Baluchistan & KPK by providing "SPEC-style" centralized security cover.

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Appendix

Detailed Methodology

The entropy-TOPSIS methods' specific steps are as follows:

1. **Develop a Standardization decision matrix**

   The standardization matrix of each dimension is obtained from the normalized value table and marked as Ai=(Atj)m×n.

2. **Weights of indicators**

   As discussed, for each indicator within the same dimension weights are determined through the entropy weighting method. All weights are obtained, using below method:

$$Wi=(wj),j=1,2,,3$$

where:

$$wj=\frac{1-ej}{\sum_{j}^{m}(1-ej)}$$

$$ej=-k\sum_{t=1}^{m}p(Atj)\ln p(Atj)$$

   ej is the entropy of indicator j. Such that, k=1/lnn ,p(A^' tj) reflects the proportion of each co-factor in time t in the j indicator. The entropy is the disorder degree of information, the larger the entropy, the lower the contribution of such indicator in energy security evaluation.

3. **Weighted standardization decision matrix**

   For approach degrees of each dimension, the weighted standardization decision matrix is formed to obtain the entropy of each dimension.

$$Y=AiWi=(yij)m\times n$$

4. Obtaining the ideal solution

y^* ij is the positive ideal solution and it is the optimal value of the indicator, y^- ij is the negative ideal solution. These two values are obtained using equation (9).

$$\begin{cases} y^{*} ij = \max (yij) \\ y^{-} ij = \min (yij) \end{cases}, j = 1,2,3$$

5. Euclidean Distance

The Euclidean distances are calculated using equations (10), and (11).

$$D^{+} j = \sqrt{\sum_{j=1}^{n} (yij - y^{*}ij)^{2}}, \; i = 1,2, \ldots ,5$$

$$D^{-} j = \sqrt{\sum_{j=1}^{n} (yij - y^{-}ij)^{2}}, \; i = 1,2, \ldots ,5$$

6. Calculating the Approach Degree

The approach degree value of each dimension varies between [0, 1]. The higher approach degree suggests, a high PSES level, and vice versa. Further PSES reaches its highest level if the approach degree is 1, and vice versa. The approach degree values are obtained using equation (12).

$$Si = \frac{D^{-} j}{D^{-} j + D^{+} j}$$

Table A1. Raw Data of Political risk coefficient

Country Name	Indicator Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
United Arab Emirates	Political Stability and Absence of Violence/Terrorism: Estimate	0.91218	0.86325	0.89479	0.76891	0.75955	0.56475	0.61864	0.70498	0.68561	0.62048	0.64930
United Arab Emirates	Political Stability and Absence of Violence/Terrorism: Number of Sources	9	9	9	9	9	9	9	9	8	7	7
United Arab Emirates	Regulatory Quality: Estimate	0.44521	0.67099	0.77497	0.98752	1.10664	0.96907	1.01081	0.92882	0.97758	1.08591	1.01390
United Arab Emirates	Regulatory Quality: Number of Sources	9	9	9	9	9	9	9	9	9	8	8
United Arab Emirates	Political risk coefficient	0.67869	0.76712	0.83488	0.87821	0.93309	0.76690	0.81473	0.81690	0.84018	0.86871	0.84375
Saudi Arabia	Political Stability and Absence of Violence/Terrorism: Estimate	-0.46480	-0.48069	-0.43178	-0.28584	-0.62640	-0.46483	-0.63782	-0.62241	-0.60589	-0.61747	-0.58386
Saudi Arabia	Political Stability and Absence of Violence/Terrorism: Number of Sources	6	7	7	7	7	8	9	9	8	7	7
Saudi Arabia	Regulatory Quality: Estimate	0.02482	0.09909	0.07969	-0.00610	0.02144	0.07530	-0.00278	-0.07776	-0.07036	0.26343	0.33571
Saudi Arabia	Regulatory Quality: Number of Sources	6	7	7	7	7	8	8	8	8	7	7
Saudi Arabia	Political risk coefficient	-0.21999	-0.19080	-0.17605	-0.14597	-0.30248	-0.19477	-0.33898	-0.36610	-0.33813	-0.17702	-0.12407
South Africa	Political Stability and Absence of Violence/Terrorism: Estimate	0.02403	-0.02539	-0.04629	-0.14639	-0.21299	-0.14150	-0.27756	-0.22778	-0.26767	-0.24082	-0.70658
South Africa	Political Stability and Absence of Violence/Terrorism: Number of Sources	9	9	9	9	9	9	9	9	8	7	7
South Africa	Regulatory Quality: Estimate	0.44641	0.39866	0.38048	0.23083	0.22431	0.13006	0.15288	-0.02823	0.02303	0.03506	-0.07315
South Africa	Regulatory Quality: Number of Sources	10	10	10	10	10	10	10	10	10	9	8
South Africa	Political risk coefficient	0.24633	0.19780	0.17832	0.05215	0.01717	0.00142	-0.05101	-0.12275	-0.10617	-0.08564	-0.36875
Oman	Political Stability and Absence of Violence/Terrorism: Estimate	0.43244	0.46208	0.45953	0.73491	0.78334	0.76005	0.75438	0.64772	0.58753	0.42699	0.50667
Oman	Political Stability and Absence of Violence/Terrorism: Number of Sources	7	7	7	7	7	7	6	6	6	5	5
Oman	Regulatory Quality: Estimate	0.31984	0.46674	0.47120	0.68847	0.57045	0.60673	0.41886	0.17132	0.29043	0.45894	0.32979
Oman	Regulatory Quality: Number of Sources	7	7	7	7	7	7	6	6	7	6	5
Oman	Political risk coefficient	0.37614	0.46441	0.46537	0.71169	0.67690	0.68339	0.58662	0.40952	0.42756	0.44442	0.41823
Kuwait	Political Stability and Absence of Violence/Terrorism: Estimate	0.31110	0.20361	0.16606	0.14901	-0.21342	-0.04968	-0.04587	0.10160	0.19264	0.25093	0.29902
Kuwait	Political Stability and Absence of Violence/Terrorism: Number of Sources	7	7	7	7	7	7	7	7	6	5	5
Kuwait	Regulatory Quality: Estimate	0.07987	-0.04033	-0.07397	-0.14755	-0.17668	-0.07800	-0.06402	0.02366	0.06281	0.28709	0.17478
Kuwait	Regulatory Quality: Number of Sources	7	7	7	7	7	7	7	7	7	6	6
Kuwait	Political risk coefficient	0.19549	0.08164	0.04604	0.00073	-0.19505	-0.06384	-0.05494	0.06263	0.12273	0.27065	0.23125
Qatar	Political Stability and Absence of Violence/Terrorism: Estimate	1.17473	1.22360	1.21255	0.97746	0.99663	0.90023	0.66116	0.66357	0.70010	0.68641	0.95788
Qatar	Political Stability and Absence of Violence/Terrorism: Number of Sources	7	8	8	8	8	8	8	8	7	6	6
Qatar	Regulatory Quality: Estimate	0.49654	0.79584	0.74128	0.56962	0.67446	0.69226	0.41631	0.59680	0.67746	0.85275	0.86345
Qatar	Regulatory Quality: Number of Sources	7	8	8	8	8	8	8	8	8	7	7
Qatar	Political risk coefficient	0.83564	1.00972	0.97691	0.77354	0.83555	0.79625	0.53874	0.63019	0.68803	0.77598	0.90704

Table A2. Normalized Value of Political risk coefficient

	United Arab Emirates	Saudi Arabia	South Africa	Oman	Kuwait	Qatar
2011	0.635738409	0.456002074	0.549266809	0.5752284	0.53909713	0.66712728
2012	0.653424358	0.461839927	0.539559331	0.5928816	0.5163276	0.70194368
2013	0.666976523	0.464790472	0.535664988	0.5930732	0.50920872	0.69538268
2014	0.675642407	0.470805044	0.510429859	0.6423375	0.50014604	0.65470793
2015	0.686618418	0.439504508	0.503433159	0.6353792	0.46098995	0.66710908
2016	0.653380102	0.461046971	0.500284892	0.6366788	0.48723148	0.65924963
2017	0.662945557	0.432203623	0.489797746	0.6173244	0.48901179	0.6077472
2018	0.663379437	0.426779274	0.475449629	0.5819037	0.51252546	0.62603711
2019	0.668036514	0.432374593	0.478765901	0.5855116	0.5245463	0.63760596
2020	0.673741531	0.464596733	0.48287221	0.5888833	0.55413049	0.65519553
2021	0.6687502	0.475186	0.42625	0.583646	0.5462508	0.6814072

For example, Political risk coefficient r for United Arab Emirates in 2011, the equation is as follows:

$$r = \frac{\textit{Raw value of political risk coefficient in 2011-(-2.5)}}{2.5-(-2.5)}$$

where, - 2.5 and 2.5 are the lower and upper limits of political risk coefficient.

Table A3. Raw values of all indicators

Year	A_{11}	A_{12}	A_{12}	A_{21}	A_{22}	A_{23}	A_{31}	A_{32}	A_{33}	A_{41}	A_{42}	A_{43}	A_{51}	A_{52}	A_{53}
	Tons	%	%	%	%	%	%	%	10^4 PKR	%	Ton/10^3 PKR	Ton/10^3 PKR	Ton	-	-
2011	1.0000	0.0258	0.9173	0.5201	0.7050	0.0530	0.1806	0.2921	0.0000	0.3793	0.0000	0.0000	0.8347	0.4140	0.1339
2012	0.8631	0.0199	1.0000	0.3735	0.3672	0.2434	0.2773	0.5825	0.0759	0.3381	0.1478	0.2280	0.8110	0.6533	0.0485
2013	0.7945	0.1125	0.9680	0.4559	0.5403	0.2621	1.0000	0.5992	0.1489	0.3735	0.3795	0.4540	0.8838	0.6461	0.0000
2014	0.7467	1.0000	0.9156	0.0000	0.9666	0.1452	0.7639	0.6579	0.1702	0.6861	0.6244	0.5990	1.0000	0.2760	0.1225
2015	0.7503	0.8938	0.7374	0.4135	0.6078	0.1178	0.5835	1.0000	0.2590	0.5608	0.6844	0.6577	0.8968	0.2614	0.4232
2016	0.4732	0.7414	0.5253	0.5294	0.4038	0.2194	0.6049	0.7330	0.4029	0.4163	0.6487	0.5857	0.2999	0.8283	0.5751
2017	0.4947	0.7323	0.2857	0.2218	0.2442	0.0545	0.2735	0.3884	0.4748	0.0000	0.6381	0.6353	0.0000	1.0000	0.6200
2018	0.4123	0.6916	0.0000	1.0000	0.3541	0.0000	0.1324	0.3143	0.6971	0.0521	0.6169	0.7048	0.1051	0.7141	0.8649
2019	0.2324	0.3435	0.1199	0.5147	0.0000	0.6865	0.2638	0.6805	0.8153	0.4267	0.7832	0.7833	0.2079	0.3596	0.9212
2020	0.0000	0.0338	0.2352	0.4461	0.7599	1.0000	0.5374	0.8828	0.7957	1.0000	1.0000	0.9316	0.5236	0.0000	0.9972
2021	0.1445	0.0000	0.1342	0.3470	1.0000	0.4588	0.0000	0.0000	1.0000	0.6426	0.9924	1.0000	0.0191	0.3714	1.0000

Table A4: Weights and ideal solutions of each indicator

Indicator	Weight	Negative Ideal Solution	Positive Ideal Solution
A11	0.1531	0.0000	0.1531
A12	0.5738	0.0000	0.5738
A13	0.2732	0.0000	0.2732
A21	0.1299	0.0000	0.1299
A22	0.5172	0.0000	0.5172
A23	0.3529	0.0000	0.3529
A31	0.6146	0.0000	0.6146
A32	0.1313	0.0000	0.1313
A33	0.2541	0.0000	0.2541
A41	0.2936	0.0000	0.2936
A42	0.5117	0.0000	0.5117
A43	0.1946	0.0000	0.1946
A51	0.3983	0.0000	0.3983
A52	0.2182	0.0000	0.2182
A53	0.3834	0.0000	0.3834

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