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Postgraduate Programme in *Enterprise Risk Management*

Master's Dissertation

Using Energy Security Indicators to Hedge Against Energy Risks

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Abstract

Energy is indispensable for economic growth and productivity, it is a key factor in the functioning of any modern economy. Energy is the necessary power needed for the operation in all sector of the economy, for example, fuel and electricity is required in transportation, heating and lighting, fuel and electricity is required for the production of goods and services, etc... However, these sources of energy are not always available and their supply can be disrupted for many reasons. To ensure long and short-term energy security, many countries and entities are striving to mitigate any disruption and the risks associated with uncertainty to access reliable, affordable, and clean energy sources.

Moreover, our interconnected economy and dependence on energy in all sectors make us more vulnerable to geopolitical crises and energy interference. This has stressed the need for a proper, efficient, and effective measure to reduce the risk exposure and energy crises. An example of energy insecurity is clearly illustrated by the Russian & Ukrainian crises, where the military intervention has created a geopolitical conflict leading to sanctions and the disruption of the energy supply.

Therefore, the use of energy risk indicators as hedging strategies can help to minimize not only the financial risks caused by energy price fluctuations for energy-intensive industries but also assist in enhancing risk management and financial success for both countries and entities.

This article presents energy security indicators in the context of mitigating energy risks at both the national and entity levels. It begins by introducing and describing energy, energy risk, and energy security indicators, then analyse each indicator based on its characteristic and ability to prevent energy supply disruptions and to cope with such disruptions, and lastly compare the energy security of some industrialized countries base on the selected security indicator data collected.

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Contents

Chapter 1: Introduction

Energy is a measurable property that is transferred to a body or physical system, giving it the ability to do work. This energy can be seen in the form of heat and light. It can take many forms, such as electrical, mechanical, chemical, thermal, or nuclear, and can be converted from one form to another, but cannot be created or destroyed.

The unit of measurement for energy in the International System of Units (SI) is the Joule (J), and also other ways such as Barrel of oil, Calorie, Horsepower, Kilowatt-hour (kWh), Kilowatt (kW), Megajoule (MJ), Megawatt (MW).

Common forms of energy include the kinetic energy of a moving object, the potential energy stored by an object the elastic energy stored in a solid object, chemical energy associated with chemical reactions, the radiant energy carried by electromagnetic radiation, and the internal energy contained within a thermodynamic system.

All living organisms constantly take in and release energy. Human civilization requires energy to function, which they get from energy resources such as fossil fuels, nuclear energy, and renewable energy. The Earth's climates and ecosystems have processes that are driven either by the energy received from the Sun or by geothermal energy.

Thus, when energy resources are in short supply or are disrupted for one or other reason, it always costs more to acquire them. This shortage and uncertainty have a direct consequence on the economy of a country and businesses for example manufacturing become expensive. Countries that experience energy insecurity usually have a lower industrial output.

Here is an example of the four industries that consume the most energy.

1-The chemical industry: which consists of the production of products including ammonia, chlorine, alkaline, ethylene, etc...

2-The petroleum and coal industry: is the process of transforming crude petroleum into component products.

3-The paper industry: Those are papermaking and pulping of wood to prepare the fiber turned into paper.

4-Primary metal industry: which consists of iron and steel mills, alumina and aluminum production and processing, foundries, etc.

Eurostat has presented the below data as the total final energy consumption by the industrial sector in Europe for 2020.

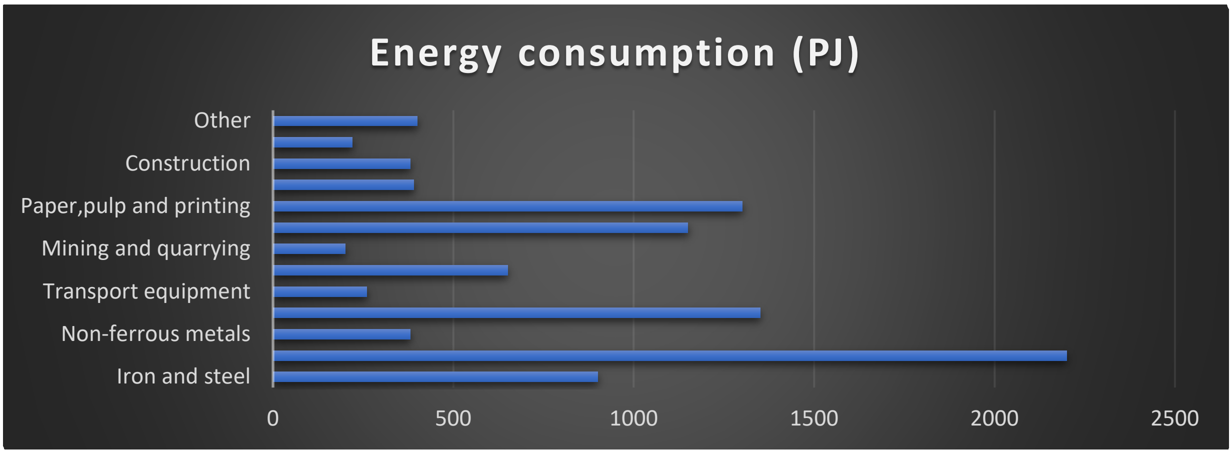

Figure 1: Energy consumption by industrial sector in Europe for 2020.
Source data : Eurostat

In the figure above, we can observe that the chemical and petrochemical industry in Europe requires the most energy to function around 2250 (PJ) in 2020 followed by the non-metallic minerals, paper pulp, and printing as well as food and beverages industries which are all essential for our daily life and activities.

The figure below shows the percentage shares of industrial energy consumption by the four major types of industries in 2021:

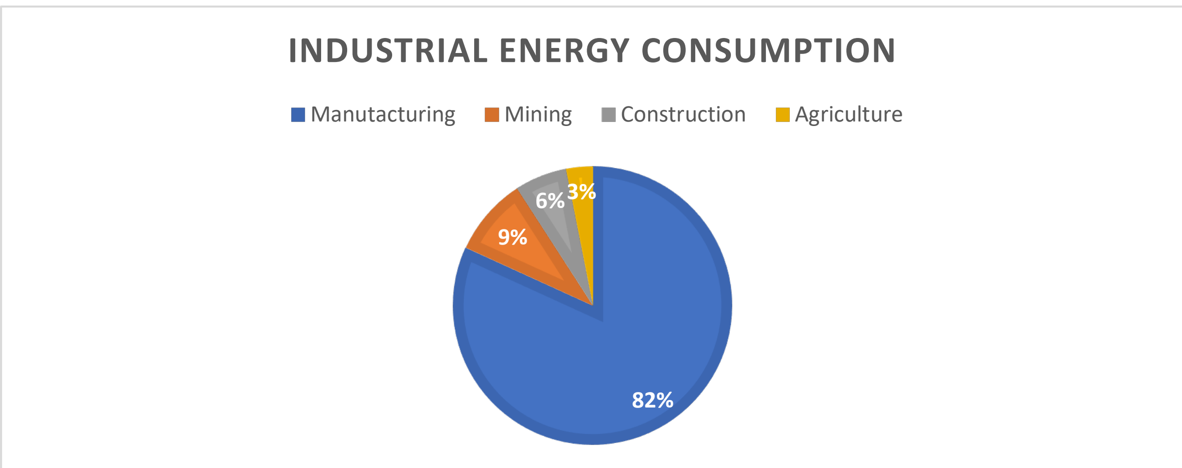

Figure 2: Industrial energy consumption by the four major types of industries in 2021.

Source data: Eurostat

We can also observe from the above figure that manufacturing requires almost 82% of the energy for their functioning.

Consequently, countries must take energy security seriously because energy risks such as energy prices increasing can have a major effect on economic growth, stability, and national security.

The Iraqi and Ukrainian crises are some of the illustrations where the lack of proper energy risk mitigation after or during the war led to the energy crisis and economic complications:

In the Iraq crisis, after Iraq's alleged development of weapons of mass destruction in March 2003, United States forces attacked Iraq to destroy Iraqi weapons of mass destruction and to end the dictatorial rule of Saddam Hussein.

That war had significant short and long terms consequences on energy.

On the Oil price, the oil price has increased suddenly in the short term due to the concerns about supply disruptions as Iraq was one of the world's largest oil producers and the war led to uncertainty about its future production capacity. The threat of war also caused speculation in oil markets.

Geopolitically, the war had implications for energy with the interruption of oil transportation as Iraq was an important oil producer and transit country for oil and gas exports.

The war has also substantially participated in the reduction of foreign investment in Iraq's energy sector, with companies hesitant to invest in a country with significant political instability. This has delayed the development of Iraq's oil and gas resources and has impacted the global energy markets in the long term.

Also, the war-damaged Iraq's energy infrastructure, including pipelines and refineries. Making it difficult for Iraq to increase its oil production capacity and export levels.

The Iraq war has highlighted the vulnerability of global energy markets to geopolitical events and raised concerns about the reliability of Middle Eastern oil supplies and increased the focus on diversifying energy sources.

The so call Ukraine crisis was the consequence of relations between Russia and Ukraine becoming hostile after the 2014 Ukrainian revolution, which was followed by Russia's annexation of Crimea from Ukraine, and the war in Donbas, in which Russia assisted the separatist fighters of the Donetsk People's Republic and the Luhansk People's Republic had significant consequences on energy, particularly in Europe.

For the Gas supplies: Ukraine was a major transit country for Russian natural gas exports to Europe. The crisis has resulted in instabilities to gas supplies, with Russia cutting off gas supplies to Ukraine in 2014 due to a pricing argument. This has affected the availability of gas to some European countries that rely on Russian gas via pipelines that cross Ukrainian territory.
On energy security: The crisis has stressed Europe's dependence on Russian gas and the need for diversification of energy sources.
The Prices: The crisis has led to increased gas prices in most parts of Europe due to supply disruptions and uncertainty about future supplies.
Geopolitically, The crisis has led to a deterioration in relations between Russia and the West, with economic sanctions being imposed on Russia by Western countries. This has affected the energy industry, with some Western companies being forced to withdraw from Russia and energy projects.
It is, therefore, imperative for governments, businesses, and individuals to reduce the impact of a crisis or other risks related to energy uncertainty by using strategies, processes, and mechanisms such as energy security indicators. These indicators measure the availability, affordability, and reliability of energy sources, as well as a country's or entity's ability to respond to energy supply disruptions.
Commonly used energy security indicators include energy intensity, energy diversification, and energy efficiency, however, the choice of indicators depends to some extent on the energy security policies of a country or entity and the definition of energy security that is being used.
More recent academic research has attempted to expand the scope of energy security focusing on the entire energy system, from primary energy resource acquisition to final energy consumption, and has proposed that energy security is not just about ensuring a reliable supply of fuel, but also ensuring that there is reliable infrastructure in place to carry energy to the end user (Jones & Paul E. Dodds, 2017)
The objective of the following is to provide a review of energy security indicators. Chapter two presents a comprehensive list of energy security indicators and their calculation method found in the literature, Chapter-three describes in detail a selected number of energy security indicators based on their risk avoidance characteristics followed by the classification of a group of 10 industrialized countries based on energy security indicators data collected in each country for a comparative analysis. In Chapter Four the result is discussed and finally, the conclusion is made in Chapter Five.

Chapter 2: Literature Review

The IEA executive director was asked in an interview ["What are the concerns of Energy Ministers?". Her response: "It's always about energy security. Always."] (Ms. Maria van der Hoeven)

Energy security has become a major focus of both national and international energy policies and is now seen as a key component of overall security by many governments, energy-intensive industries, and businesses. However, many countries still struggling to manage the risks associated with energy supply and price volatility, as evidenced by recent assessments.

An evaluation of energy security among nations revealed that only one out of 162 countries achieved an "Excellent" rating, while 37 countries were given a "Good" score. The rest of the countries had weaknesses in their energy security, with a stark contrast between countries in Western Europe and North America, which performed well, and those in Africa and Asia, which performed poorly. The majority of countries, including those in Europe, were categorized as "Limited". This indicates that many countries are having difficulty putting in place proper energy security management. (Wang & Kan Zhou, 2017)

Similarly, a study of 16 indicators showed that the energy security of many countries has decreased over time and that the level of energy security can differ greatly between countries. This was demonstrated by the five categories of energy security identified: low energy security (e.g. China and India), consumption-oriented energy security (e.g. industrialized nations), security based on high and very high energy production (e.g. OPEC members), and high and diversified energy security (e.g. Norway). (Huibin, et al., 2020)

Furthermore, the four most powerful economies in the European Union (the UK, France, Germany, and Italy) have seen less variation in energy security over 23 years compared to other nations. This could be due to their greater reliance on nuclear and renewable energy sources, which may explain the increased reliance on energy imports. Other elements that have a major effect on energy security include energy intensity, GDP per capita, and carbon intensity. Countries in the former Eastern Bloc have had particular struggles with energy. (Radovanović, et al., 2017)

Energy security is a complex concept that is dependent on the context and must be viewed from various angles. Different socio-demographic and regional factors can affect how energy security is perceived, and elements such as gender and age can also have an impact. Additionally, the amount of oil a country imports is linked to its level of worry about different aspects of energy security, including access, cost, and fairness. Therefore, to comprehend energy security, it is necessary to take into account a variety aspects of a system.
This suggests that understanding energy security requires considering a range of factors and how they interact in specific contexts (Knox-Hayes, et al., 2013)

Also, it is essential to understand that energy security is a combination of the tangible elements of energy systems and the perceived security. To accurately evaluate energy security, it is necessary to find a balance between these two factors and to take into account the particular environment in which energy systems are operating. This could include combining indicators into combined indices or stories that give a thorough understanding of energy flows and their importance for societies. Additionally, it is important to identify weaknesses in energy systems and to pick indicators that can act (Cherp & Jessica Jewell, 2010)

Owain Jones and Paul E. Dodds have suggested the "FOUR A" framework to assess energy security, which consists of four components: availability, affordability, accessibility, and acceptability. Availability is about having enough energy sources, affordability is about the cost of these resources, accessibility is about making sure everyone has access to energy, and acceptability is about reducing negative effects such as pollution and environmental damage. To measure energy security, indicators are often used to compare the energy security
(Jewell, et al., 2012)

Additionally, there is the International Index of Energy Security Risk which is a tool that uses two indicators - energy security risk scores and international energy security rankings - to evaluate the energy security of different countries. These indicators provide insight into a nation's economic, political, social, and environmental structure, and can be used to inform decisions related to trade, investment, and energy agreements and contracts. The energy security risk scores and rankings can help to improve energy security by giving a comprehensive view of a country's energy security situation.
. (Kocaslan, 2014)

Conclusively, there is no single perfect measure of energy security, as it is highly dependent on the context. Therefore, using multiple indicators can give a more comprehensive view of the situation. Studies have shown that the energy demand is growing faster than production, leading to a 142% increase in international energy trade by 2050 compared to 2008. Oil production is likely to be concentrated in a few countries until 2030, but this could be changed if stricter climate policies are put in place,
(Kruyt, et al., 2009)

Markus B. and Christoph B. have highlighted the necessity of more sophisticated energy security indicators to make more precise evaluations of energy security. A potential solution to this problem is to combine multiple energy security indicators into one comprehensive indicator. This would eliminate the need to make compromises between different indicators and provide a simpler way to evaluate energy security. However, combining different indicators can be a difficult task as it requires a high degree of subjectivity when assigning weights to the various indicators being taken into account
(Bortolamedi & Christoph Böhringer, 2014)

Thus, It is important to recognize that energy security indicators that are not based on microeconomics are usually just descriptive and do not give an opinion on whether energy market interference is desirable. Without a way to turn indicators into a shared financial metric, it is hard to compare different indicators. Furthermore, there is a lack of economic research on energy security indicators, making it hard to determine the size and scope of externalities and to create suitable measures. Without a strong microeconomic basis
Without a rigorous microeconomic foundation, the concept of energy security may remain vague and difficult to operationalize (Böhringera & Markus Bortolamedib, 2015)

Azzuni and Breyer have created a comprehensive energy security index that can be applied to all countries worldwide. It consists of 15 dimensions, such as availability, diversity, cost, technology and efficiency, location, timeframe, resilience, environment, health, culture, literacy, employment, policy, military, and cyber security. They used a numerical method to calculate the index, which is based on several criteria from reliable sources and can be normalized for energy security analysis. The energy security index was created by assigning numerical indicators to each dimension, normalizing and standardizing them to a percentage,

and multiplying them by their corresponding weights. The values for each dimension were then combined using their weights to form the overall index.
(Azzuni & Christian Breyer, 2020)

Moreover, the International Energy Agency (IEA) has developed the Model of Short-Term Energy Security (MOSES) to assess and compare the energy security of IEA member countries. Rather than ranking countries, MOSES defines each country's energy security profile and categorizes countries with similar risks and resilience factors. This evaluation is based on quantitative indicators that measure both the risks of energy supply disruptions and the capacity of an energy system to handle such disruptions.
The results of this evaluation at the national level suggest that the interpretation of energy security indicators can be influenced by the specific context in which they are being used. In some cases, a higher value of an indicator may be interpreted as both a positive and a negative indication of energy security (Kanchana & Hironobu Unesaki, 2015)

It is therefore essential to create energy security indicators based on a comprehensive evaluation system that takes into account the major vulnerabilities of essential energy systems for businesses. Companies that use derivatives to manage their risk can be beneficial. It would be beneficial to look into the success of hedging in the energy industry, as the market has evolved and the economic situation is changing quickly. In this unstable economic situation, the need for energy resources is expected to keep growing, and energy companies will need to adopt more sustainable investments.
(Samitas, et al., 2011).

The following are nine main energy indicator groups for gas: macro-economic indicators (such as energy intensity, consumption/capita, import bill indicator, etc.), energy balance indicators (including production, imports, exports, transformation, conversion loss, distribution loss, energy industry use, and final consumption), reserves indicators (Indigenous production and proven gas reserves), sectoral indicators (TFC industry, households, services, power generation, etc.), diversification indicators (sources, suppliers, sectorial,

Anca C. Badea has proposed the following as the most popular general indicators.

1. **Energy intensity**:

Energy intensity is the ratio of the total primary energy supply and the gross domestic product .

A high value of energy intensity means a high quantity of energy used for a certain level of economic activity.

Measuring energy intensity is an important tool for policymakers trying to decrease energy use without reducing economic activity levels.

The calculation method is:

$$\boldsymbol{Energy\ intensity = \frac{TPES}{GDP}} \qquad \boldsymbol{Eq. 1}$$

With

TPES = Total Primary Energy Supply

GDP= Gross Domestic Product

If a manufacturing company consumes a significant amount of energy but does not produce enough goods to justify that energy consumption, the measure of energy intensity would be a valuable information.

Advantages:

The method is very simple to build and allows us to identify where energy is being wasted or where energy efficiency improvements can be made.

It can also assist in setting a target for reducing energy consumption per unit of production or output.

Disadvantages:

Energy intensity measurements only consider the relationship between energy consumption and production or output, and do not account for other factors that influence energy use, such as weather conditions or changes in production processes, also, the primary energy dependency of the economy can be underestimated by GDP's primary energy intensity.

2. **N-1 indicator:**

N-1indicator indicates that there is sufficient capacity to supply total gas demand if the largest infrastructure fails.

The calculation method is:

$$N - 1\,(\%) = \frac{IP\,m + Pm + S\,m + LNG\,m - Im - T\,out}{D\,max} * 100 \geq 100\% \qquad Eq.2$$

With **IPm**= import pipelines,

Pm=production,

Sm= storage withdrawal,

LNGm= LNG facility,

Im= largest gas infrastructure,

Tout=transmission outflow,

Dmax =demand max

Advantages:

The method is very simple to build and allows us to identify where energy is being wasted or where energy efficiency improvements can be made.

It can also assist in setting a target for reducing energy consumption per unit of production or output.

Disadvantages:

Energy intensity measurements only consider the relationship between energy consumption and production or output, and do not account for other factors that influence energy use, such as weather conditions or changes in production processes, also, the primary energy dependency of the economy can be underestimated by GDP's primary energy intensity.

3. Dependency on External Primary Energy Supply:

Dependency on external primary energy means dependency on external fossil primary energy resources such as crude oil, natural gas and coal where the governments don't have any control. Basically it shows the fossil primary energy import dependency.

Dependency on External Primary Energy Supply implies the riskiness of the higher levels of imports of fossil primary energy and the use of positive net imports for compensating the deficiency in energy imports by energy exports:

The calculation method is:

$$NID = \sum_{ff} \frac{\max(O, \mathrm{Mff} - \mathrm{Xff})}{TPES} \qquad Eq.3$$

With

NID net import dependency

ff fossil primary energy carrier

Mff total imports of fossil primary energy ff

Xff total exports of fossil primary energy ff

TPES = Total Primary Energy Supply

Advantages:

The method provides a good understanding of a country's dependence on external energy sources and the potential risks associated with that dependence, such as supply disruptions or price fluctuations, and encourages countries to diversify their energy sources, reducing their dependence on any one source and improving their energy security.

Disadvantages:

Does not account for energy efficiency improvements or changes in energy consumption configurations, which can affect a country's dependence on external energy sources, and for differences in the quality and carbon intensity of energy sources, which can affect greenhouse gas emissions.

However, measuring fuel mix diversity by Herfindahl-Hirschman prevents distinguishing primary energy alternatives.

Dependency on External Primary Energy Suppliers shows dependence on single external suppliers. Dependency on external primary energy suppliers takes into consideration the political risk of suppliers and higher values mean higher dependency on specific suppliers.

Depending on a single supplier means higher exposures to economic risks. To avoid supply shocks diversifying the suppliers is a key strategy. Dependency on external primary energy suppliers shows that a single external fossil primary energy supplier means higher price and quantity risks:

The supplier dependency calculation method is the following:

$$\boldsymbol{SDff = \sum_i ai^{HHI}\left(\frac{\max(O, Mi,ff - Xi,ff)}{\sum_i \max(O, Mi,ff - Xi,ff)}\right)2} \qquad \boldsymbol{Eq. 4}$$

With

SD Supplier dependency

Mi,ff represents fossil primary energy imports coming from supplier i

Xi,ff denotes EU's fossil primary energy exports to country i.
ai HHI supplier specific risk factor
HHI=Herfindahl – Hirschman index

Here, the fossil primary energy suppliers are considered, and renewables and nuclear are not considered.
The Composite Supplier Dependency refers to the aggregation of the external primary energy suppliers. Thus it can be considered as a weighted average
The calculation method is:

$$\boldsymbol{SD} = \sum_{ff} \frac{\sum_{f} \max(\boldsymbol{O}, \boldsymbol{Mi}, \boldsymbol{ff} - \boldsymbol{Xi}, \boldsymbol{ff})}{\sum_{ff} \sum_{i} \max(\boldsymbol{O}, \boldsymbol{Mi}, \boldsymbol{ff} - \boldsymbol{Xi}, \boldsymbol{ff})} \boldsymbol{SDff} \qquad \boldsymbol{Eq.5}$$

Here the supplier fungibility and the risks in the transport are ignored.

4. **Dependency on Primary Energy Carriers:**

Dependency on Primary Energy Carriers shows the dependence of economic, transactions on crude oil, natural gas, coal, renewable energy resources and nuclear which are stated as primary energy carriers.
The higher values of the mentioned dependence refers to higher exposures to economic risks related to the mentioned carrier. Higher values of dependency on primary energy carriers means that some of the primary energy carriers are included more referring to higher dependency on the mentioned primary energy carriers. Dependency on Primary Energy Carriers designates specific primary energy carriers reliance which is risky and is criticized because fuel mix diversity is measured by indices based on Herfindahl–Hirschman:
The calculation method of the dependency on primary energy carriers is:

$$\boldsymbol{PECD} = \sum_{f} \left(\frac{\boldsymbol{Sf}}{\boldsymbol{TPES}}\right)^{2} \qquad \boldsymbol{Eq.6}$$

With
PECD primary energy carrier dependency and
(Sf) total physical supply of primary energy carrier
TPES = Total Primary Energy Supply

Advantages:

Encourage countries to diversify their primary energy carriers, reducing their dependence on any one carrier and improving their energy security.

Disadvantages:
Does not account for energy efficiency improvements or changes in energy consumption configurations, which can affect a country's dependence on specific primary energy carriers and only considers primary energy carriers, such as coal, oil, gas, nuclear, and renewables, and does not account for the use of energy storage technologies, which can also affect energy security

5. **Shannon-Wiener Index:**

Shannon-Wiener Index:
Shannon-Wiener Index is a measure of the diversity or uncertainty of a system
It is commonly used in ecology to quantify the diversity of species within a community and can be used in energy at maximum when all the energy sources are equal and provide a comprehensive measure of energy diversity.
His calculation formula is:

$$\boldsymbol{SWI = \sum_{i=1}^{n} Pi \log(Pi)} \qquad \boldsymbol{Eq.7}$$

With
Pi=the proportion of each energy source of the countries or entity
Log = the natural logarithm

Advantages:
It takes into account both the number of different energy sources used and their relative abundance.

Disadvantage
It does not account for energy efficiency improvements or changes in energy consumption patterns, which can affect a country's energy diversity.

6. **Herfindahl-Hirschman index:**

The Energy Herfindahl-Hirschman Index (HHI) is a measure of market concentration that is commonly used in the energy industry. It is calculated in the same way as the standard HHI, but with market shares based on the total energy production or sales of each entity or country. The formula for calculating the Energy HHI is:

$$HHI = \sum_{i=1}^{n} Pi^{2} \qquad Eq.8$$

Where Pi is the market share of a company or country i based on their total energy production or sales.

Shannon-Wiener Index and completely supply-oriented Herfindahl-Hirschman Index consider energy security indirectly determining the degree of a specific country's dependence on a specific supplier

Advantage

It is easy to calculate and provide a clear measure of the market concentration of a specific source of energy and can also be used in combination with other measures.

Disadvantage

Can be influenced by measurement error and ignore the energy source differentiation.

(Badea, 2010)

The following shows more complex indicators

7. **The Energy Security Index:**

The Energy Security Index (ESI) is a measure of a country's ability to ensure a reliable and affordable supply of energy to meet its domestic needs.

The Energy Security index is calculated as follows

$$\sum_{i-1}^{n} ViXi \qquad Eq.9$$

With Vi equal to the weight of each dimension and Xi the value of each dimension and

$$Xi = \sum_{f=1}^{m} Wj - Yj \qquad \textbf{Eq. 10}$$

With Wj equal to the weight of each parameter and Yj the value of each parameter.
Yj is built by one indicator or an average of several indicators. Values of each indicator are normalized to a percentage

$$Yj = \frac{\sum_{n=1}^{0} LnYj}{n} \qquad \textbf{Eq. 11}$$

With In equal to a normalized indicator used for the specific parameter Yj and o the number of indicators.
All parameters are given equal weights (Wj) within their dimension because of a lack of data for individual weighing.
Many indicators are normalized by a max-min approach in linear regression to obtain a percentage indicator with relevance to the global achievement in that indicator.

$$Ln.Yj = \frac{Ia+Imin}{Imax-Imin} * 100\%. \qquad \textbf{Eq. 12}$$

With (In.Yj) equal to the normalized indicator, (Ia) the absolute value of the indicator, (Imin) the minimum value in the world for (Ia) and (Imax) the maximum value in the world for (Ia).

$$In.Yj = \frac{Ia+Iworst}{Ioptimal-Iworst} * 100\% \qquad \textbf{Eq. 14}$$

With (In.Yj) equal to the normalized indicator, (Ia) the absolute value of the indicator, (Iworst) the worst value in the world for this indicator (Ia) and (Ioptimal) the optimal value in the world for this indicator (Ia).

Advantage
It provides a framework for comparing energy security across different countries and can be used to identify areas where improvements can be made to ensure a more secure and sustainable energy future.

Disadvantage

Not always easy to put in place due to the data availability of each value.
(Azzuni & Christian Breyer, 2020)

Additionally, we have composite indicators which are formed when individual indicators are compiled into a single index based on the underlying model of the multi-dimensional concept that is being measured.
Composite indicators are instruments for simple comparisons of countries (regions, universities, economic sectors…) they monitor their performances and time trends and convey policy messages

The following table summarizes some indicators of the risk cover and the calculation method.

Table 1: Energy security indicators and their risk concerns

Indicators	Energy security Risk	Calculation
Energy intensity in (MJ/GBP)	Exposure to energy supply and price volatility	TPES divide by GDP
Diversity of energy sources in primary energy supply (PES)	Exposure to various primary energy sources disruptions	SWDI or HHI
Diversity of primary energy sources in carriers	Carrier Exposure to various primary energy source disruptions	SWDI or HHI
Diversity of primary energy sources in end sectors	End-user Exposure to various primary energy source disruptions	SWDI or HHI
Reserves or resource to production ratios in (Years)	Exposure to energy shocks	Reserves or resources divided by production rates

Average age of infrastructure in (years in relations to projected life time	Reliability of energy conversion and transition	The age of all infrastructural facilities
Spare capacities for electricity generation in %	Reliability of electricity generation	Installed capacity divided by the critical or average
Rate of energy sector export revenue decline in % year	Burden on energy systems associated with fast growth	The growth in energy supply (or use) in fuel, carrier or end-use
Rate of energy export revenue decline in % year	Instability associated with fast decline of energy export revenues	The change in energy export revenues year on year
Compound diversity index	Combined divert and severity concerns	Modified SWDI
Global energy trade (absolute) in Ej/year	Disruption of trade flows by various factors	Total flows of trade between regions in a given year
Global energy trade (intensity) in share(0-1)	Disruption of trade flows by various factors	Global energy trade divided by global energy supply
Geographic diversity of production	Disruption of trade flows by various factors	SWDI or HHI
Net import dependency in share(0-1)	Regional Exposure to trade disruptions by various factors	Net energy imports divided by total PES or total primary energy of a given source

Cost of energy imports in relation to GDP in share(0-1)	Regional vulnerability to trade disruptions by various factors	Energy import value divided by GDP
Cost of energy exports in relation to GDP in share(0-1)	Regional exposure to trade disruptions of energy export	Energy export value divided by GDP
Carriers dependence on imported fuels in share(0-1)	Exposure to carriers to trade disruptions	Share of energy carriers produced from imported sources divided by the total energy carrier
End-use sectors dependence imported fuels in share(0-1)	Exposure of end-use sectors to trade disruptions	Share of end user sectors produced from imported fuels
Political stability of suppliers	Political situation in supplier countries security of the energy supply	Political risk rating

Author's compilation

Moreover, the IEA has developed the Model of Short-term Energy Security (MOSES) which is a computer-based model used by the International Energy Agency (IEA) to analyze the short-term risks to the global energy system. The model was developed in the late 1990s in response to concerns about energy security following several supply disruptions in the 1990s.

MOSES is designed to simulate and analyze potential supply disruptions in the oil market, which is still the most important source of energy in the world. The model takes into account a wide range of factors that can impact oil supply and demand, including geopolitical events, weather-related disruptions, and changes in oil production and consumption patterns. It uses its data to project oil market trends and to identify potential vulnerabilities in the global energy system.

Table 2: Energy security indicators use in MOSES

Indicator	Energy Source
Net import dependence	Crude oil, Natural gas, Coal, Biomass and waste, Biofuels
Political stability of suppliers	Crude oil, Natural , gas, Coal
Proportion of offshore production	Crude oil
Volatility of domestic production	Crude oil
Oil product net import dependence	Oil products
Number of refineries	Oil products, Crude oil, Natural gas
Proportion of offshore production	Natural gas
Proportion of mining that is underground	Coal
Diversity of sources	Biomass and waste
Volatility of agricultural output	Biofuels
Unplanned outage rate	Nuclear power
Average age of nuclear power plants	Nuclear power

Author's compilation

In sum, various energy security indicators have been suggested and examined in the literature, including the "indicator for energy security" developed by Bert Kruyt, D.P. van Vuuren, H.J.M. de Vries, and H. Groenenberg. They have utilized many of the aforementioned indicators and emphasized the importance of a continuous energy supply without disruption as it is essential for our daily lives and economy to function properly.

In the following chapters, let's examine the importance of certain indicators in preventing energy supply disruptions and then selected some indicators with their relevant data from 10 of the most industrialize countries in each continent and have a comparison analysis.

Chapter 3: Description and justification of the research methodology

A comprehensive evaluation of energy security concerns requires a comparison of energy risk indicators and their effectiveness in mitigating energy risk at both the national and entity levels. Energy security indicators are metrics used to assess the stability, reliability, and affordability of a country's energy supply. These indicators serve as useful tools for understanding a country's energy security situation and for making informed policy decisions.

They are also important for identifying and managing energy price volatility, which can have a significant impact on the financial performance of energy-intensive industries.

Hedging strategies that incorporate energy risk indicators can help countries or entity to mitigate all the risks, especially the financial risks associated with the fluctuation of energy prices, and improve their overall risk management capabilities.

The following are the indicators selected.

- Net energy import dependency ratio (NEIDR)
- Energy Intensity (EI)
- The Political stability of suppliers: Diversity of energy sources in primary energy supply
- Energy Self-Sufficiency Ratio (ESR)
- Renewable Energy Share (RES)
- Reserve-to-production ratio (RPR)]

The choice was based on the fact that these indicators are part of the main group of indicators which takes into account the major exposure of essential energy systems for countries and entities. Similarly, some were used in the MOSES methodologies put in place by the IEA and other organizations to evaluate the effects of supply disruptions and advise on energy security-related policy decisions. Also, they are updated regularly to reflect the shifts in the global energy system with the findings closely monitored by policymakers and industry experts worldwide.

Additionally, the indicators chosen consider the risk factors associated with potential disruptions in energy supply, as well as a country's ability to handle such disruptions similar to the MOSES method.

The MOSES method follows a four-dimensional approach to evaluate short-term energy security, which includes both external and domestic factors, the process involves the selection of 35 indicators based on existing research and expert advice from the IEA. And the aggregation of these indicators into three groups based on the observed ranges of the indicator values in IEA countries.

In the MOSES method, expert judgments are often utilized to determine the "safe" levels of risk or "adequate" resilience capacities.

The process later generates a categorization of energy security profiles for each country that takes into account how certain risks may compound each other and how certain resilience capacities may mitigate them. The countries are then categorized into three to five energy security profiles for each energy source or fuel, based on overall risk exposure and resilience capacities. These profiles are labeled with letters A to E, with A representing the lower risk/higher resilience profile (higher energy security) and E representing the higher risk/lower resilience profile (lower energy security).

In our analysis, we will use a descriptive method as we aim to examine the differences and behaviors of the selected countries base on the data collected from the energy security indicators, the method is suitable for processing historical data and identifying the trends or relationships between samples. the data is collected from 10 countries chosen because they are part of the top 10 best performing in each continent for each selected energy security indicator. The advantage of using this method is that it is easy to understand, a straightforward method providing a comprehensive overview of a dataset, patterns, and a base for comparison with other datasets over time. Useful for assessing changes in the data against other industries, entities, or countries. However, this method provides only a summary of the data and not a deeper comprehension of the relationships or patterns in the data for example, it cannot determine causality or infer relationships between variables. It may also oversimplify complex data, which can lead to a loss of important information.

Chapter 4: Presentation and analysis of the research data

In the following, after a review of the selected indicators and the risk that they mitigate, a calculation is performed with the data of energy security indicators collected from the 10 countries chosen and the result allowed a classification from 1 to 10 in a descending arrangement table, then all the ranking tables are pool together and the final total is used to compare the energy risk security of the selected countries.

1. **<u>Net energy import dependency ratio</u>**: NEIDR

NEIDR measures the proportion of a country's energy consumption that must be imported, taking into account both the energy produced domestically and the energy imported. The formula is:

$$\boldsymbol{NEIDR = \frac{Net\ Imports\ of\ energy}{(Total\ Energy\ consumption - Total\ Energy\ Production)} * 100 \qquad Eq.15}$$

The Net energy import dependency ratio identifies the extent to which a country relies on imported energy sources.

With

- Net imports of energy: which is the difference between total energy imports and total energy exports, measured in tons of oil equivalent (toe) or in any other unit of energy
- Total primary energy supply: the total amount of energy that a country produces and imports, measured in tons of oil equivalent (toe) or in any other unit of energy

The result is expressed as a percentage, which indicates the proportion of a country's energy needs that are met by imports.

The Advantage of using this method is that It is a straightforward method to assess a country's dependence on foreign sources of energy and can be used to compare energy import levels between different countries and regions.

The disadvantage is that It does not take into account the diversity of energy sources or the potential for domestic energy production

The net energy import dependency ratio Can be used as a tool to mitigate energy risk by reducing dependence on imported energy and minimizing the exposure to the risks associated with volatile energy prices, geopolitical tensions, and supply disruptions

Table 3: 2021 Net energy import dependency ratio

Countries	**Year**	**Net imports (TWh)**	**Primary energy consumption (TWh)**	**Total energy production 2021-(Twh)**	**NEIDR-2021**
South Africa	2021	-3.15	1382.897	1552.1	1.86%
Canada	2021	-47.01	3871.156	6859.62	1.57%
France	2021	14.28	2612.792	1418.76	1.20%
United Kingdom	2021	6.22	1994.278	1319.99	0.92%
Russia	2021	-8.67	8693.623	18786.73	0.09%
India	2021	-0.11	9841.214	5564.83	0.00%
Saudi Arabia	2021	0.3	3006.726	7791.59	-0.01%
China	2021	-17.7	43790.895	39552.87	-0.42%
Germany	2021	-26.81	3511.587	1196.32	-1.16%
United States	2021	39.31	25825.46	28819.73	-1.31%

Example calculation 2021: NEIDR China $= \frac{-17.7}{(43790.895-39552.870)}$ *100 = - 0.42%

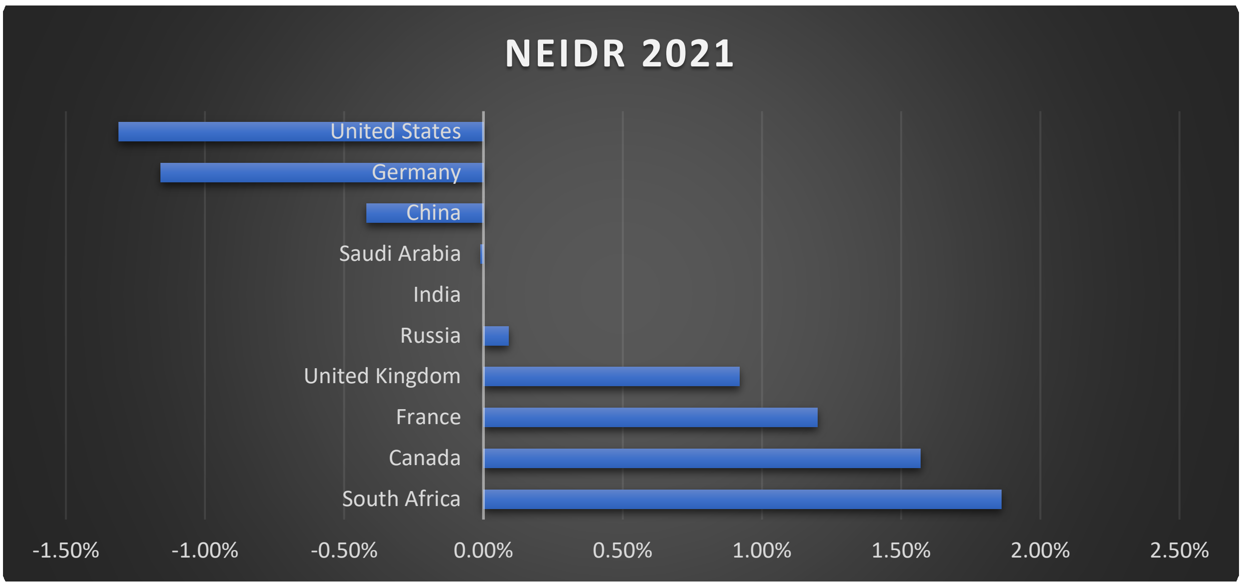

Figure 3: 2021 Net energy import dependency ratio

In the above figure, we can observe that South Africa that needs the highest proportion of its energy around 2% to be met by the energy imported.

Table 4: 2021(NEIDR) Ranking

Countries	NEIDR 2021	Rank
United States	-1.30%	1
Germany	-1.20%	2
China	-0.40%	3
India	0.00%	4
Saudi Arabia	0.00%	5
Russia	0.10%	6
United Kingdom	0.90%	7
France	1.20%	8
Canada	1.60%	9
South Africa	1.90%	10

The United States has the first rank in 2021 meaning that is the country with the lowest proportion of energy consumption coming from importation.

Table 5: 2011 Net energy import dependency ratio

Countries	Year	Energy imports, net (% of energy use) 2011	Primary energy consumption 2011(TWh)	Total energy production 2011-(Twh)	NEIDR 2011
South Africa	2011	-15.5	1444.96	1718.86	5.70%
Saudi Arabia	2011	-232.74	2551.07	7678.46	4.50%
United Kingdom	2011	30.84	2356.06	1621.27	4.20%
Canada	2011	-52.96	3896.99	5469.88	3.40%
France	2011	46.06	2881.31	1518.99	3.40%
Germany	2011	60.56	3710.59	1449.53	2.70%
China	2011	11.86	31333.57	30767.77	2.10%
India	2011	29.38	6650.71	4231.07	1.20%
Russian Federation	2011	-80	8080.63	16150.85	1.00%
United States	2011	18.55	25726.06	22891.2	0.70%

Example calculation 2011 NEIDR Canada $=\frac{-52.96}{(3896.988-5469.878)}$*100=3.4%

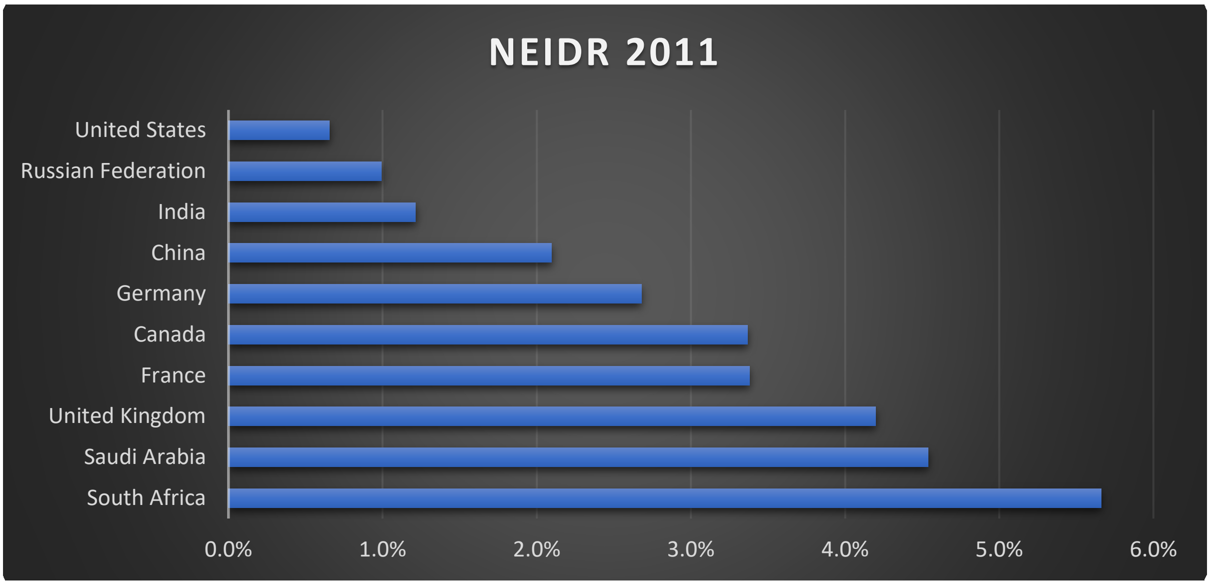

Figure 4: 2011 Net energy import dependency ratio

Similarly, in 2011 we can observe that South Africa is still the country with the highest proportion of its energy around 5.7 % to be met by the energy imported. However, we can observe also a decrease of almost 3% of that external dependency over the 10 years (2011 - 2021)

Table 6: 2011 (NEIDR) Ranking

Countries	NEIDR 2011	Rank 2011
United States	0.70%	1
Russian Federation	1.00%	2
India	1.20%	3
China	2.10%	4
Germany	2.70%	5
France	3.40%	6
Canada	3.40%	7
United Kingdom	4.20%	8
Saudi Arabia	4.50%	9
South Africa	5.70%	10

In 2011 the United States was again the country with the lowest proportion of energy consumption coming from importation.

Table 7: 2011 & 2021 Net energy import dependency ratio and % change

Countries	NEIDR 2011	NEIDR 2021	% change
South Africa	5.66%	1.86%	-2.04%
Canada	4.54%	1.57%	-1.89%

France	4.20%	1.20%	-2.50%
United Kingdom	3.38%	0.92%	-2.67%
Russia	3.37%	0.09%	-36.44%
India	2.68%	0.00%	N/A
Saudi Arabia	2.10%	-0.01%	211.00%
China	1.21%	-0.42%	3.88%
Germany	0.99%	-1.16%	1.85%
United States	0.65%	-1.31%	1.50%

We can observe from the above table that Saudi Arabia has considerably changed their energy importation habit over the last 10 years.

Author's compilation
Source data: our world in data.org.
U.S. Energy Information Administration
data.worldbank.org

2. **Energy Intensity (EI):**

Energy Intensity is a measure of the amount of energy supply per unit of economic output, such as GDP.

The EI is calculated as the total primary energy consumption TPEC divided by the gross domestic product of a given region or country. It indicates the amount of energy necessary to produce each unit of GDP.

Energy intensity measure also the energy efficiency that expresses the amount of energy required to produce a unit of GDP

The calculation method is:

$$\textit{Energy intensity} = \frac{TPEC}{GDP} \qquad Eq.16$$

With

TPEC = Total Primary Energy consume

GDP= Gross Domestic Product

A high value of energy intensity means a high quantity of energy used for a certain level of economic activity.

Measuring energy intensity is an important tool for policymakers trying to decrease energy use without reducing economic activity levels.

Let's assume that a manufacturing company consumes a significant amount of energy but does not produce enough goods to justify that energy consumption. In that case, knowing the measure of energy intensity would be valuable information.

The advantage of the method is that is very simple to build and it identifies where energy is being wasted or where energy efficiency improvements can be made. It can also assist in setting a target for reducing energy consumption per unit of production or output.

However, its disadvantage is that its measurements only consider the relationship between energy consumption and production or output, and may not account for other factors that influence energy use, such as weather conditions or changes in production processes.

Energy Intensity can be used as a tool to mitigate energy risk by improving energy efficiency, reducing energy consumption, and minimizing the exposure to the risks associated with volatile energy prices and supply disruptions

Table 8: 2021 Energy Intensity (EI)

Countries	**Primary energy consumption (TWh)**	**GDP in Millions dollars**	**EI_2021**
United Kingdom	1994.28	3,123,231.00	0.00064
Germany	3511.59	4,262,767.00	0.00082
France	2612.79	2,957,423.00	0.00088
United States	25825.46	23,315,100.00	0.00111
Canada	3871.16	2,001,487.00	0.00193
China	43790.9	17,759,307.00	0.00247
India	9841.21	3,150,307.00	0.00312
South Africa	1382.9	418,907.00	0.00330
Saudi Arabia	3006.73	868,586.00	0.00346
Russia	8693.62	1,836,631.00	0.00473

Example calculation 2021: United states EI $=\frac{25825.46}{23315100}$ =0.00123

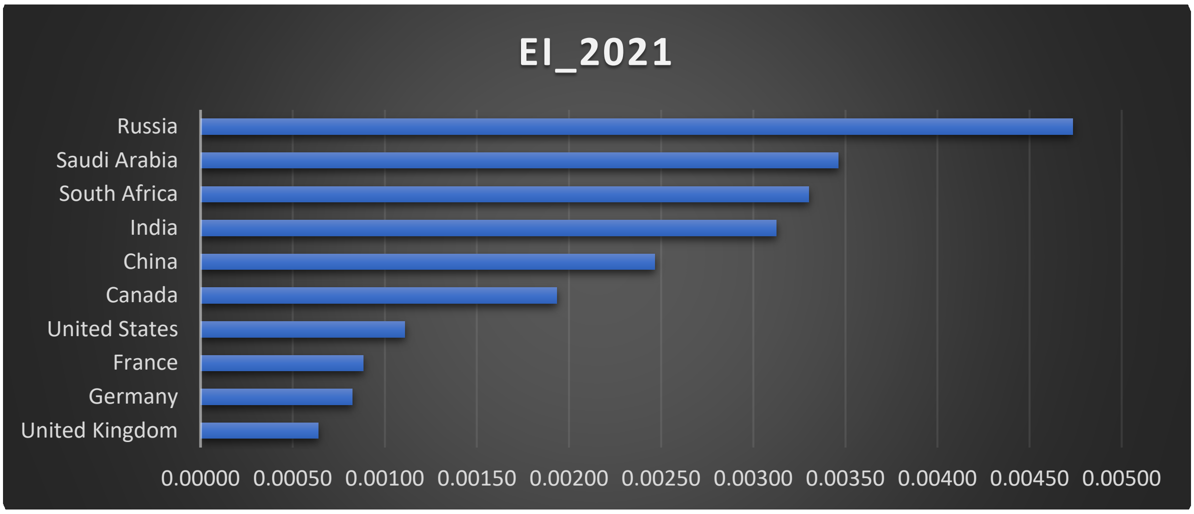

Figure 5: 2021 Energy Intensity

From the above figure we can observe that Russia have a high value of energy intensity meaning that they used a high quantity of energy for a certain level of economic activity.

Table 9: 2021 (EI) Ranking

Countries	EI_2021	Rank
United Kingdom	0.00064	1
Germany	0.00082	2
France	0.00088	3
United States	0.00111	4
Canada	0.00193	5
China	0.00247	6
India	0.00312	7
South Africa	0.00330	8
Saudi Arabia	0.00346	9
Russia	0.00473	10

The united kingdom was the first country here in 2021 in terms of efficiency by using less energy per GDP produced.

Table 10: 2011 Energy Intensity (EI)

Countries	Primary energy consumption 2011(TWh)	GDP in Millions dollars 2011	EI_2011
United Kingdom	2356.06	2667317	0.00088
Germany	3710.59	3748655	0.00099
France	2881.31	2864653	0.00101
United States	25726.06	15599700	0.00165
Canada	3896.99	1793327	0.00217
South Africa	1444.96	458708	0.00315

India	6650.71	1823052	0.00365
Saudi Arabia	2551.07	676635	0.00377
Russian Federation	8080.63	2046621	0.00395
China	31333.57	7492212	0.00418

Example calculation 2011: China EI $=\frac{31333.57}{7492212}=0.0041$

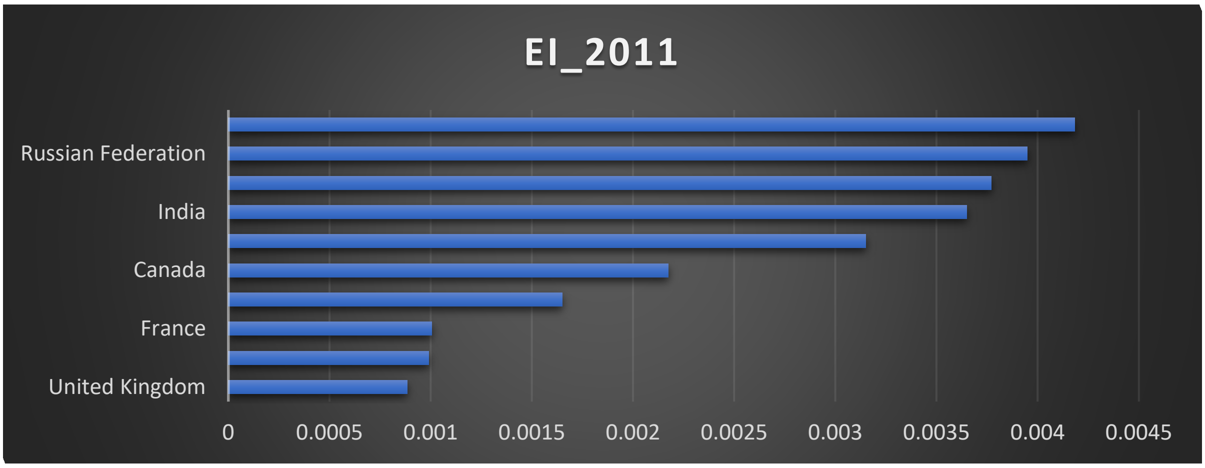

Figure 6: 2011 Energy Intensity

Here in 2011 we can observe that it was china which was using a highest quantity of energy for a certain level of economic activity.

Table 11: 2011 (EI) Ranking

Countries	EI_2011	Rank
United Kingdom	0.000883307	1
Germany	0.000989846	2
France	0.001005815	3
United States	0.001649138	4
Canada	0.00217305	5
South Africa	0.003150065	6
India	0.003648119	7
Saudi Arabia	0.003770231	8
Russian Federation	0.003948279	9
China	0.004182152	10

Here in 2011 while the united kingdom was the first country using less energy per GDP produced amount the 10 selected, China was the one using more energy per GDP produced.

Table 12: 2011& 2021 Energy Intensity (EI) % change :

Countries	**EI_2011**	**EI_2021**	**% change**
United Kingdom	0.00088	0.00064	-38%

Germany	0.00099	0.00082	-21%
France	0.00101	0.00088	-15%
United States	0.00165	0.00111	-49%
Canada	0.00217	0.00193	-12%
South Africa	0.00315	0.00247	-28%
India	0.00365	0.00312	-17%
Saudi Arabia	0.00377	0.0033	-14%
Russian Federation	0.00395	0.00346	-14%
China	0.00418	0.00473	12%

We can observe from the table above that the United States is the country which has improved the most its usage of energy per GDP production over the last 10 years.

Author's compilation
Source data: (Anon., 2023)

3. Political stability of suppliers

The political stability and regulatory environment for the energy sector can have a significant impact on energy risk. A stable political environment and a well-defined regulatory framework can help to reduce regulatory uncertainty, increase investor confidence, and promote long-term planning and investment in the energy sector.
The Political Stability Index (PSI) measure the likelihood of political instability or instability risk in a given country.
His advantage is that he provides a quantitative measure of political stability, which can be useful for comparing countries and in this context, countries that supply energy recourses and track changes over time. This can help governments, businesses, and investors to make informed decisions based on the level of risk in a particular country.
However, it has a disadvantage that it is based on subjective assessments of political stability, which can vary depending on the individual or organization providing the assessment. This can lead to inconsistencies in the index and undermine its reliability as a measure of political stability, so it is important to be aware of its limitations and potential biases and should be used in conjunction with other measures.

To mitigate the political and regulatory risks in energy, a country or entity can diversify its energy portfolio and invest in geographically diverse energy assets, adopt risk management strategies such as hedging and insurance, and engage with relevant stakeholders to promote a stable political and regulatory environment for the energy sector.

Here we used the political stability index (-2.5 weak and 2.5 strong) of the global economy.com where the index is set up based on the indices such as the corruption perceptions-transparency international, the political rights, and civil liberty, competitiveness, the cost of starting a business and the shadow economy.

Table 13: 1996 -2021 Political stability of suppliers

Countries	Political stability, 1996-2021	Global rank	Available data
Canada	0.94	35	1996 - 2021
Germany	0.76	52	1996 - 2021
UK	0.54	68	1996 - 2021
France	0.37	78	1996 - 2021
USA	0	96	1996 - 2021
China	-0.48	133	1996 - 2021
Saudi Arabia	-0.58	139	1996 - 2021
India	-0.62	143	1996 - 2021
Russia	-0.65	146	1996 - 2021
South Africa	-0.71	151	1996 - 2021

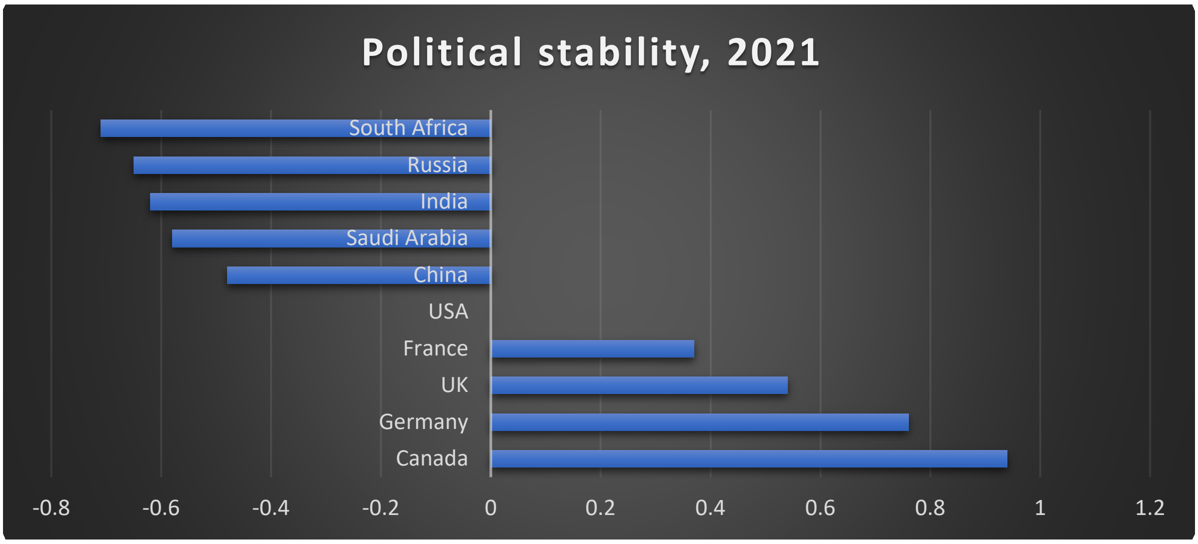

Figure 7: 1996 -2021 Political stability of suppliers

The figure shows that Canada has a better political stability and regulatory environment for the energy sector with a higher score than the 10 countries chosen.

Table 14: 1996-2021 ranking

Countries	Political stability, 1996-2021	Rank
Canada	0.94	1

Germany	0.76	2
UK	0.54	3
France	0.37	4
USA	0	5
China	-0.48	6
Saudi Arabia	-0.58	7
India	-0.62	8
Russia	-0.65	9
South Africa	-0.71	10

Canada is classified first here in terms of better political stability and regulatory environment for the energy sector.

Author's compilation
Source: (Anon., 2023)

4. **Diversity of energy sources in primary energy supply**

The diversity of suppliers is calculated using the Herfindahl-Hirschman index, which is a measure of the concentration of supply. It is calculated in the same way as the standard HHI

$$\boldsymbol{HHI = \sum_{i=1}^{n} Pi^2} \qquad \boldsymbol{Eq. 8}$$

Where Pi is the market share of a company or country i based on their total energy production or sales.
Herfindahl-Hirschman Index considers energy security indirectly determining the degree of a specific country's dependence on a specific supplier.

A higher HHI (Herfindahl-Hirschman Index) market concentration index indicates that a market is more concentrated among a few dominant suppliers and less competition in the market.

The advantage of the method is that it provides a good understanding of a country's dependence on external energy sources and the potential risks associated with that dependence, such as supply disruptions or price fluctuations, and encourages countries to diversify their energy sources, reducing their dependence on any one source and improving their energy security.

And on the other hand, its disadvantage is that it does not account for energy efficiency improvements or changes in energy consumption configurations.

Energy demand depends on different socioeconomic factors such as population, urbanization, industrialization, net capital income and development of technologies, etc…

The diversity of energy sources in the primary energy supply can be used as a tool to hedge against energy risk by reducing dependence on any one particular energy source and increasing the resilience and flexibility of energy supply chains.

Table 15: 2020 market concentration index

Countries	Indicator Name	HHI_2020
Germany	HH Market concentration index	0.037
France	HH Market concentration index	0.047
United Kingdom	HH Market concentration index	0.049
China	HH Market concentration index	0.05
Russian Federation	HH Market concentration index	0.051
United States	HH Market concentration index	0.054
India	HH Market concentration index	0.058
South Africa	HH Market concentration index	0.064
Saudi Arabia	HH Market concentration index	0.088
Canada	HH Market concentration index	0.491

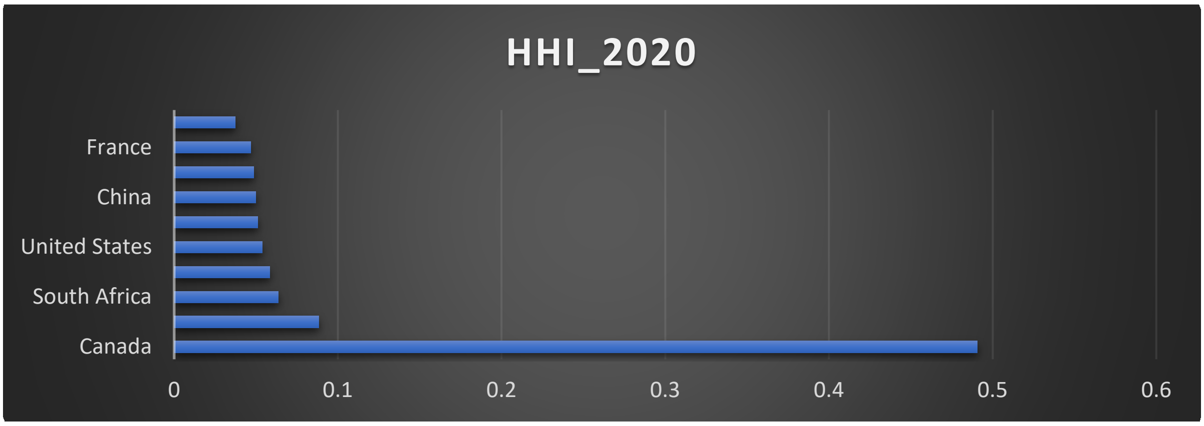

Figure 8: 2020 market concentration index

From the above figure we observe that Canada has the highest market concentration showing that there were a few dominant suppliers and less competition in their market in 2020.

Table 16: 2020 ranking

Countries	HHI_2020	Rank
Germany	0.037	1
France	0.047	2
United Kingdom	0.049	3
China	0.05	4
Russian Federation	0.051	5
United States	0.054	6
India	0.058	7
South Africa	0.064	8
Saudi Arabia	0.088	9
Canada	0.491	10

In 2020 Germany was the country with more competitors in their supplier market amount the 10 countries chosen.

Table 17: 2011 market concentration index

Countries	Indicator Name	
Russian Federation	HH Market concentration index	0.0349
Germany	HH Market concentration index	0.0371
India	HH Market concentration index	0.0429
United Kingdom	HH Market concentration index	0.0503
France	HH Market concentration index	0.0506
United States	HH Market concentration index	0.0549
China	HH Market concentration index	0.0608
South Africa	HH Market concentration index	0.0713
Saudi Arabia	HH Market concentration index	0.0799

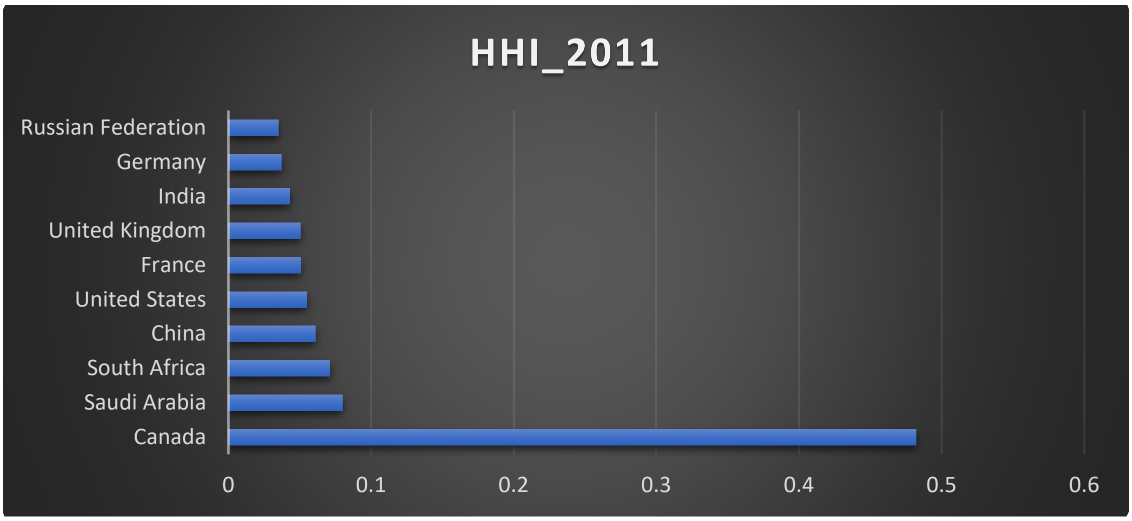

Figure 10: 2011 market concentration index

Over the 10 years, we can observe from the figure that Russia was the country with the most competition in the market supplier and that from 2011 to 2020 Germany took the first place from the 10 countries chosen.

Table 18: 2011 HHI ranking

Countries	HHI_2011	Rank
Russian Federation	0.03488565	1
Germany	0.03707535	2
India	0.04288191	3
United Kingdom	0.05034963	4
France	0.05060822	5
United States	0.05486748	6
China	0.06080515	7
South Africa	0.07125277	8
Saudi Arabia	0.07987871	9
Canada	0.48227715	10

In 2011 the table shows that Russia was the country with the most competitor in the supplier market.

Table 19: 2011& 2020 market concentration index % change

Countries	HHI_2011	HHI_2020	% change
Germany	0.03488565	0.03745268	6.90%
France	0.03707535	0.04663674	20.50%
United Kingdom	0.04288191	0.04868812	11.90%
China	0.05034963	0.04968547	-1.30%
Russian Federation	0.05060822	0.05106972	0.90%
United States	0.05486748	0.05375087	-2.10%
India	0.06080515	0.05843234	-4.10%
South Africa	0.07125277	0.06366477	-11.90%
Saudi Arabia	0.07987871	0.08835666	9.60%
Canada	0.48227715	0.49070348	1.70%

The table above shows how in 2011 and 2020 France increase their market concentration among a few suppliers whereas South Africa allowed more competitors in the market and here the energy markets.

Author's compilation
Source data: (Anon., 2023)

5. **Energy Self-Sufficiency Ratio (ESR):**

Energy Self-Sufficiency Ratio is a measure of a country's ability to produce and meet its own energy needs from domestic resources without relying on imports. It is calculated by dividing the total primary energy production of a country by its total primary energy consumption.

A higher ESR indicates that a country is more self-sufficient in meeting its energy needs from domestic resources, whereas a lower ESR indicates that a country is more dependent on imported energy sources.

The ESR is an important indicator of a country's energy security, as it reflects the level of resilience to supply disruptions and price volatility in global energy markets..

The ESR is calculated as the total primary energy supply (TPES) divided by the total primary energy consumption (TPEC). It indicates the amount of primary energy that is produced within a given region or country compared to the amount of energy it consumes.

$$ESR = \frac{TPES}{TPEC} \qquad \textbf{Eq. 17}$$

As an advantage, the Energy Self-Sufficiency Ratio can help a country to reduce its dependence on imports and minimize the risk of supply disruptions, and also encourage the development of domestic energy production,

However, its disadvantage is that it can rely on limited resource availability and lead to higher energy costs and reduced energy security.

Table 20: 2021 Energy Self-Sufficiency Ratio (ESR)

Countries	Total energy production 2021- (Twh)	Primary energy consumption (TWh)	ESR_2021
Germany	1196.32	3511.59	0.34
France	1418.76	2612.79	0.54
India	5564.83	9841.21	0.57
United Kingdom	1319.99	1994.28	0.66
China	39552.87	43790.9	0.9
United States	28819.73	25825.46	1.12
South Africa	1552.1	1382.9	1.12
Canada	6859.62	3871.16	1.77
Russia	18786.73	8693.62	2.16
Saudi Arabia	7791.59	3006.73	2.59

Example calculation for 2021: ERS Germany = $\frac{1196.320}{3511.587}$ =0.341

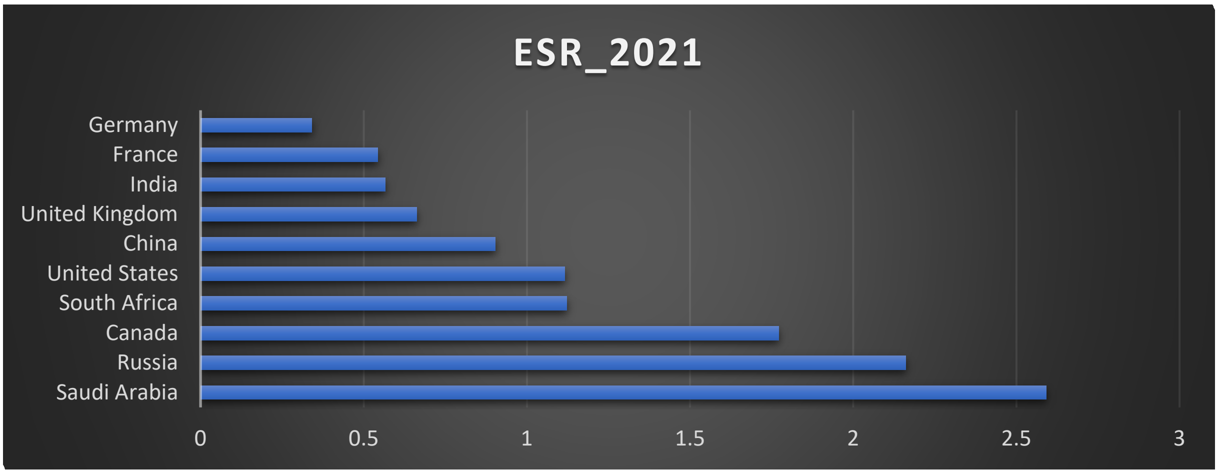

Figure 11: 2021 Energy Self-Sufficiency Ratio (ESR)

Here the figure and the table below indicate that Saudi Arabia has the highest amount of energy it produced to compare its consumption in 2021.

Table 21: 2021 (ESR) ranking

Countries	ESR_2021	Rank
Saudi Arabia	2.59	1
Russia	2.16	2
Canada	1.77	3
South Africa	1.12	4
United States	1.12	5
China	0.9	6
United Kingdom	0.66	7
India	0.57	8
France	0.54	9
Germany	0.34	10

Table 22: 2011 Energy Self-Sufficiency Ratio (ESR)

Countries	Total energy production 2011-(Twh)	Primary energy consumption 2011(TWh)	ERS_2011
Canada	5469.88	3896.99	1.4
China	30767.77	31333.57	0.98
France	1518.99	2881.31	0.53
Germany	1449.53	3710.59	0.39
India	4231.07	6650.71	0.64
Russian Federation	16150.85	8080.63	2

Saudi Arabia	7678.46	2551.07	3.01
South Africa	1718.86	1444.96	1.19
United Kingdom	1621.27	2356.06	0.69
United States	22891.2	25726.06	0.89

Example calculation for 2011: ERS Canada = $\frac{5469.88}{3896.99}$ =1.40

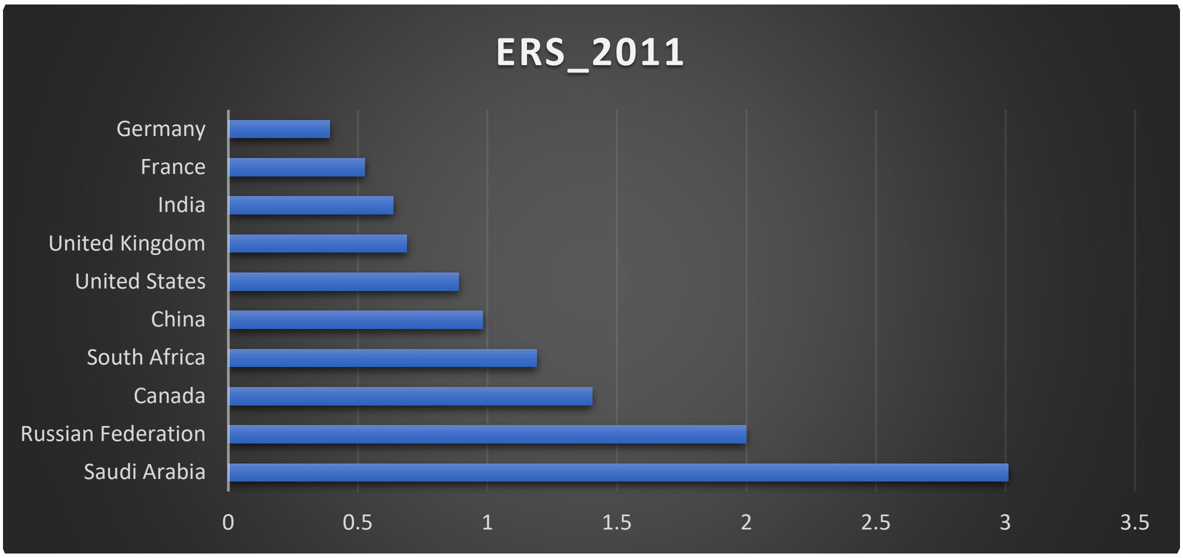

Figure 12: 2011 Energy Self-Sufficiency Ratio (ESR)

In 2011 Saudi Arabia had already the highest amount of primary energy produced compared with the energy that they consume and as shown in the table below is classified first amount the 10 countries in the selection.

Table 23: 2011 (ESR) ranking

Countries	ERS_2011	Rank
Saudi Arabia	3.01	1
Russian Federation	2	2
Canada	1.4	3
South Africa	1.19	4
China	0.98	5
United States	0.89	6
United Kingdom	0.69	7
India	0.64	8
France	0.53	9
Germany	0.39	10

Table 24: 2011 & 2021 Energy Self-Sufficiency Ratio (ESR) % change

Countries	ERS_2011	ESR_2021	%Charge
Canada	3.01	2.591	**-16.15%**
China	1.999	2.161	**7.51%**

France	1.404	1.772	**20.79%**
Germany	1.19	1.122	**-5.99%**
India	0.982	1.116	**12.01%**
Russian Federation	0.89	0.903	**1.49%**
Saudi Arabia	0.688	0.662	**-3.96%**
South Africa	0.636	0.565	**-12.51%**
United Kingdom	0.527	0.543	**2.91%**
United States	0.391	0.341	**-14.67%**

Here in the table above we can observe that France has improved their production capacity or reduced their consumption over the years 2011 to 2021 compared to Canada which has either reduced its production or increased its consumption over those years.

Author's compilation
Source data: (Anon., 2023)

6. **Renewable Energy Share (RES)**

Renewable Energy Share (RES) is a ratio that measures the proportion of a country's total energy supply that is generated from renewable energy sources. It is calculated by dividing the total amount of energy generated from renewable sources (such as wind, solar, hydro, geothermal, and biomass) by the total primary energy supply of a country, including both renewable and non-renewable sources.

$$RES = \frac{PESR}{TPES}. \qquad \boldsymbol{Eq. 18}$$

A higher RES indicates that a country is generating a larger proportion of its energy from renewable sources, which as benefits can reduce greenhouse gas emissions, improved energy security, and enhanced energy independence. Also, can stimulate the development of renewable energy industries, creating new jobs and economic opportunities.
However, there are also some challenges associated with increasing the RES, such as the intermittency of some renewable sources, which can require additional investments in energy storage and backup capacity. In addition, the cost of renewable energy technologies can be higher than traditional fossil fuels, although this is changing as renewable technologies become more cost-competitive.

Table 25: 2021 Renewable Energy Share (RES)

Countries	Renewables (% equivalent primary energy)	Total energy production 2021-(Twh)	Primary energy supply from renewable sources	RES_2021
Middle East (BP)	0.96	1552.1	14.82	0.01
South Africa	3.41	1196.32	40.78	0.034
Russia	6.62	6859.62	454.13	0.066
India	9.31	1319.99	122.9	0.093
United States	10.66	1418.76	151.18	0.107
France	13.67	5564.83	760.77	0.137
China	14.95	28819.73	4307.47	0.149
United Kingdom	17.95	7791.59	1398.32	0.179
Germany	19.45	18786.73	3654.61	0.195
Canada	29.89	39552.87	11821.74	0.299

Example calculation for 2021 : RES Canada = $\frac{11821.736}{39552.870}$=0.299

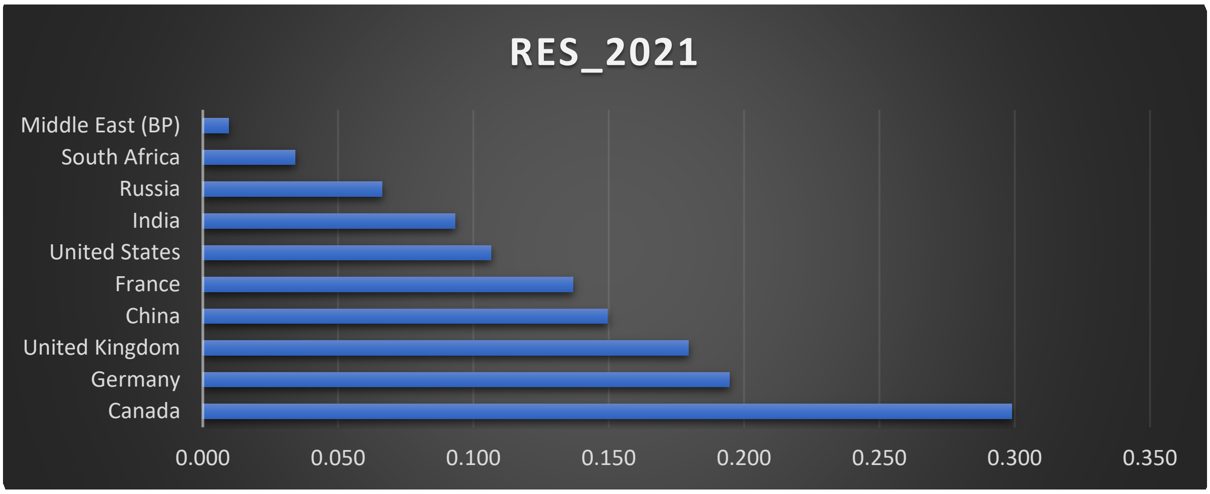

Figure 13: 2021 Renewable Energy Share (RES)

The figure above shows that Canada have largest proportion of its energy coming from renewable sources compare to the other 10 countries, and it is classify fist in the table below.

Table 26: 2021 RES ranking

Countries	RES_2021	Rank
Canada	0.299	1
Germany	0.195	2
United Kingdom	0.179	3
China	0.149	4

France	0.137	5
United States	0.107	6
India	0.093	7
Russia	0.066	8
South Africa	0.034	9
Middle East (BP)	0.01	10

Table 27: 2011 Renewable Energy Share (RES)

Countries	**Renewables (% equivalent primary energy)**	**Total energy production 2011-(Twh)**	**Primary energy supply from renewable sources**	**RES_2011**
Saudi Arabia	0.00058	7678.46	0.04	5.83E-06
South Africa	0.69835	1718.86	12	0.01
United Kingdom	4.89113	1621.27	79.3	0.05
Russia	5.58528	16150.85	902.07	0.06
United States	6.89732	22891.2	1578.88	0.07
China	7.0842	30767.77	2179.65	0.07
France	7.18552	1518.99	109.15	0.07
India	7.50134	4231.07	317.39	0.08
Germany	10.56697	1449.53	153.17	0.11
Canada	28.62637	5469.88	1565.83	0.29

Example calculation for 2021 : RES Germany = $\frac{153.17}{1449.53}$=0.11

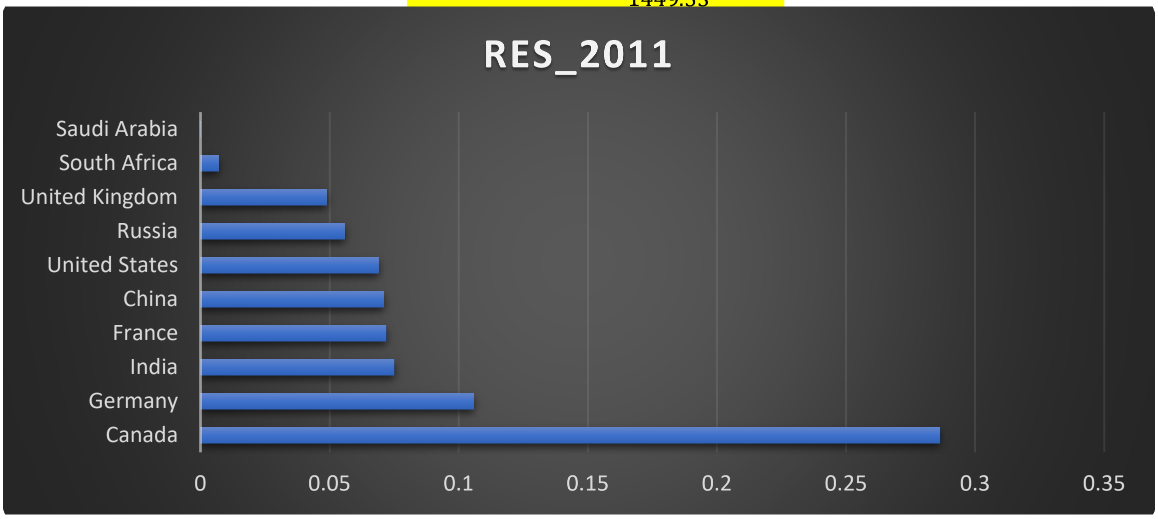

Figure 14: 2011 Renewable Energy Share (RES)

The figure above shows that Canada has the largest proportion of its energy coming from renewable sources compared to the other 10 countries, and it is classified first in the table below.

Table 28: 2011 RES ranking

Countries	**RES_2011**	**Rank**
Canada	0.29	1
Germany	0.11	2
India	0.08	3
France	0.07	4
China	0.07	5
United States	0.07	6
Russia	0.06	7
United Kingdom	0.05	8
South Africa	0.01	9
Saudi Arabia	0	10

Table 29: 2011 & 2021 Renewable Energy Share (RES) % change

Countries	**RES_2011**	**RES_2021**	**% change**
Canada	0.286	0.299	4%
China	0.071	0.149	52%
France	0.072	0.137	48%
Germany	0.106	0.195	46%
India	0.075	0.093	19%
Russia	0.056	0.01	-459%
Saudi Arabia	0	0.066	100%
South Africa	0.007	0.034	79%
United Kingdom	0.049	0.179	73%
United States	0.069	0.107	36%

During 2011 and 2021 from the above data and table we can observe that Russia had the highest decrease in the proportion of its energy coming from renewable sources compared to the middle east and here Saudi Arabia which improve considerably their proportion of its energy coming from renewable sources.

Author's compilation
Source data: ourworldindata.org

7. **Reserve-to-production ratio (RPR)**

The reserves-to-production ratio measures the number of years a natural resource will last if consumption rates stay the same.

It measures the amount of oil reserves a country has in relation to its current production rate. The formula is:

$$RPR = \frac{Oil\ Reserves}{Oil\ Production} \qquad \boldsymbol{Eq. 19}$$

The reserves-to-production ratio is commonly used to estimate how many years' worth of oil an entity or a country has.

The (RPR) is also a measure of the number of years that a country or entity's reserves of a particular energy source, such as oil or gas, are expected to last at current production rates. It can be used as a tool to hedge against energy risk by indicating the future availability and price of energy resources.

For example, if a country has 10 billion barrels of oil reserves and produces 1 billion barrels of oil per year, its R/P ratio would be 10 (i.e. the reserves would last for 10 years at the current rate of production).

Its advantages are that it can predict future supply and are very useful for planning to compare the availability of different non-renewable resources in different regions or countries.

However, it does not account for the potential of substitute resources or technologies, such as renewable energy or new types of fuel. These could alter the demand for non-renewable resources and affect the R/P ratio.

Table 30: 2021 Reserve-to-production ratio (RPR)

Countries	**Oil reserves, 2021**	**Yearly Oil Production (Barrels per day)**	**RPR_2021**
South Africa	0.02	0.14	0.15
France	0.06	0.13	0.45
Germany	0.12	0.21	0.57
UK	2.5	1.08	2.31
United States	44.418	14.84	2.99
India	4.6	1.02	4.53
China	26.02	4.91	5.3
Russia	80	11.26	7.1
Saudi Arabia	258.6	12.4	20.85
Canada	170.3	4.6	37.05

Sample computation 2021: Saudi Arabia RPR $= \frac{258.200}{12.403}$ =20 years

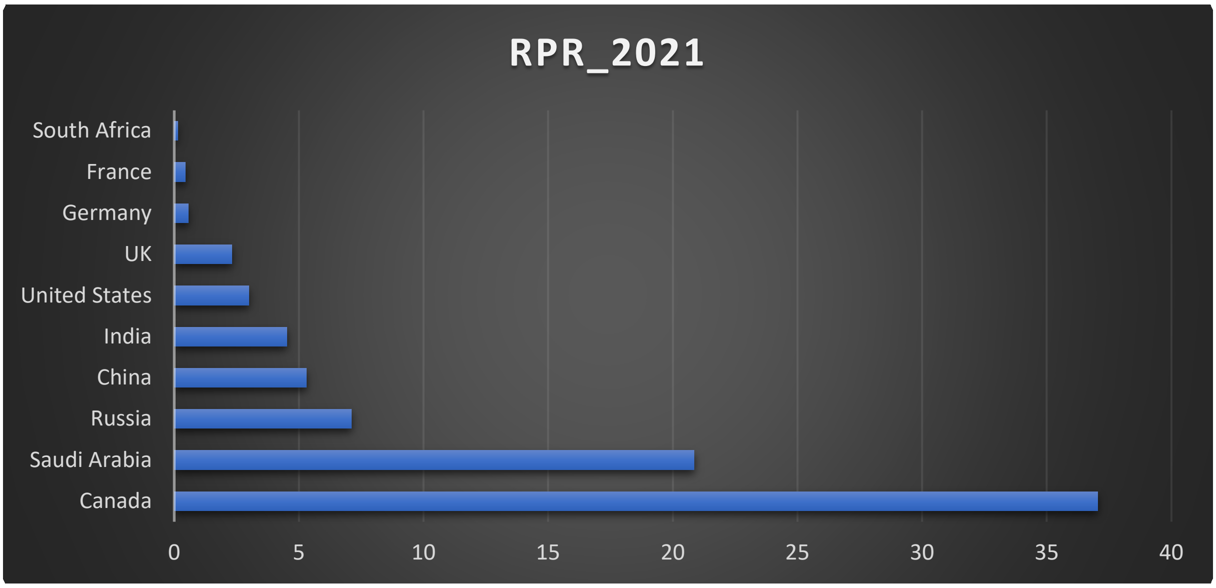

Figure 15: 2021 Reserve-to-production ratio (RPR)

The figure above shows how Canada has the highest reserves-to-production ratio compared to the other 10 countries and classify as first in the table below.

Table 31: 2021 RPR ranking

Countries	RPR_2021	Rank
Canada	37.05	1
Saudi Arabia	20.85	2
Russia	7.1	3
China	5.3	4
India	4.53	5
United States	2.99	6
UK	2.31	7
Germany	0.57	8
France	0.45	9
South Africa	0.15	10

Table 32: 2013 Reserve-to-production ratio (RPR)

Countries	Oil reserves, 2013 (bbl)	Yearly Oil Production (Barrels per day)	RPR_2013
South Africa	0.02	0.14	0.11
France	0.09	0.13	0.64
Germany	0.25	0.21	1.2
UK	3.12	1.08	2.88
United States	20.68	14.84	1.39
India	5.48	1.02	5.39
China	17.3	4.91	3.53

Russia	80	11.26	7.1
Saudi Arabia	267.9	12.4	21.6
Canada	173.1	4.6	37.66

Example calculation for 2013: France RPR $= \frac{0.09}{0.133}$ =0.64 years

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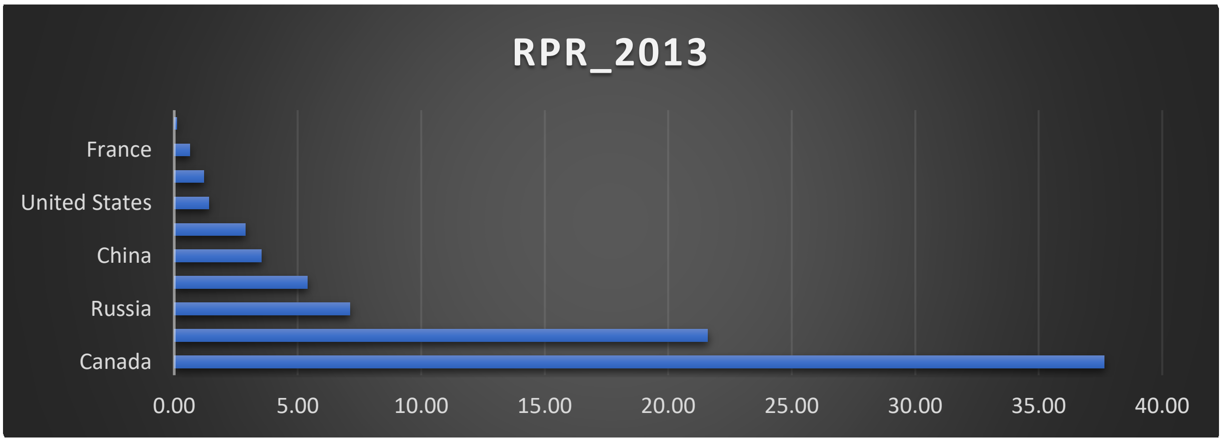

Figure 16: 2013 Reserve-to-production ratio (RPR)

Likewise, we observe from the above figure that Canada had in 2013 the highest reserves-to-production ratio compared to the other 10 countries and that it did not change to 2021 and classify as first in the table below.

Table 33: 2013 (RPR) ranking

Countries	RPR_2013	Rank
Canada	37.66	1
Saudi Arabia	21.6	2
Russia	7.1	3
India	5.39	4
China	3.53	5
UK	2.88	6
United States	1.39	7
Germany	1.2	8
France	0.64	9
South Africa	0.11	10

Table 34: 2013& 2021 Reserve-to-production ratio (RPR) % change

Countries	RPR_2013	RPR_2021	% change
South Africa	0.11	0.15	25%
France	0.64	0.45	-42%
Germany	1.2	0.57	-112%
UK	2.88	2.31	-25%

United States	1.39	2.99	53%
India	5.39	4.53	-19%
China	3.53	5.3	34%
Russia	7.1	7.1	0%
Saudi Arabia	21.6	20.85	-4%
Canada	37.66	37.05	-2%

We can observe from the table above that Germany is the country that has the most increase his reserve from 2013 to 2021.

Author’s compilation
Sources data: (Anon., 2023)

Chapter 5: Discussion of findings and results

NEIDR: Net energy import dependency ratio

EI :Energy Intensity

PS: Political stability of suppliers

HHI: Diversity of energy sources in primary energy supply

ESR: Energy Self-Sufficiency Ratio

RES: Renewable Energy Share

RPR: Reserve-to-production ratio

The result was ranked from 1 to 10 in a descending arrangement.

Table 35: Ranking summary 2020 -2021

Countries	NEIDR	EI	PS	HHI	ESR	RES	RPR	TOTAL
Germany	2	2	2	1	10	2	8	**27**
Canada	9	5	1	10	3	1	1	**30**
UK	7	1	3	3	7	3	7	**31**
China	3	6	6	4	6	4	4	**33**
USA	1	4	5	6	5	6	6	**33**
France	8	3	4	2	9	5	9	**40**
Russia	6	10	9	5	2	8	3	**43**
India	4	7	8	7	8	7	5	**46**
Saudi Arabia	5	9	10	9	1	10	2	**46**
South Africa	10	8	7	8	4	9	10	**56**

Table 36: Ranking summary 2011 -2013

Countries	NEIDR	EI	PS	HHI	ESR	RES	RPR	TOTAL
Canada	7	5	1	10	3	1	1	**28**
Germany	5	2	2	2	10	2	8	**31**
Russia	2	9	9	1	2	7	3	**33**
USA	1	4	5	6	6	6	7	**35**
India	3	7	8	3	8	3	4	**36**
UK	8	1	3	4	7	8	6	**37**
France	6	3	4	5	9	4	9	**40**

China	4	10	6	7	5	5	5	**42**
Saudi Arabia	9	8	10	9	1	10	2	**49**
South Africa	10	6	7	8	4	9	10	**54**

According to the selected energy security indicators and data collected from the 10 countries in our analysis, Canada ranked first for the data collected from 2011 to 2021. Overall, Canada has the best energy security mitigation compared to the other 10 countries selected. This is because Canada needed a low proportion of its energy consumption from importation compared to South Africa which is the country depending the most on imported energy than the others, United States is the country that needed the lowest proportion of its energy consumption coming from importation.

Canada also had a relatively medium usage of its energy for its GDP production compared to Russia and China which used a high quantity of energy for their economic activity.

Moreover, Canada has better political stability and regulatory environment for the energy sector compared to Saudi Arabia and Russia which have shown the worst result for that indicator.

But, Canada's result on market concentration shows that it has a monopoly control in general in their market in comparison to Russia, France, and Germany which are more competitive in their market structure and hence the energy market.

However, Canada shows a strong primary energy produced compared to the energy that they consume with the best being Saudi Arabia and Russia which produce more energy than they consume according to the indicator for the relevant period.

Also, Canada's result shows that the largest proportion of its energy is coming from renewable sources, the same for Germany and UK, and the highest reserves-to-production ratio compared to the other countries selected.

In general, Canada is considered to have a fairly high level of energy security due to its diverse energy resources, stable political environment, and strong regulatory framework.

Canada has a well-developed energy infrastructure, including pipelines, transmission lines, and storage facilities, and is the world's fifth-largest energy producer, with abundant reserves of oil, natural gas, and renewable energy sources such as hydropower, wind, and solar.

Conversely, the country's dependence on fossil fuels for energy production rise concerns about greenhouse gas emissions and climate change, and its dependency on the United States as the main export market for oil and natural make him vulnerable to geopolitical risks or disruptions in the US market.

Next, Germany which has the second good result from our ranking for the period 2011 to 2021 have now complex energy security with several challenges due to its reliance on energy imports which have been emphasized by the Russian- Ukrainian crisis, and its dependency on Russia's Gaz, In 2011, following the Fukushima nuclear disaster in Japan, the German government decided to turn off their nuclear power by 2022 and increase the share of renewable energy sources. However Germany is one of the countries that has a well-developed energy infrastructure and a strong regulatory framework, though its domestic energy resources are limited and it relies heavily on energy imports, particularly natural gas, Germany is now investing in alternative energy sources to reduce their reliance on Russian gas.

The United States is considered to have a relatively high level of energy security due to its abundant domestic energy resources, diversified energy mix, and advanced energy infrastructure.
The United States has a well-developed energy infrastructure including pipelines, refineries, storage facilities, and transmission lines, which facilitate the efficient transportation and distribution of energy, and is one of the world's largest producers of natural gas and crude oil. It has also significant reserves of coal and renewable energy sources such as wind, solar, and hydroelectric power. The country has also a strong regulatory framework that ensures the safety and security of its energy supply.
Conversely, the United States faces the challenges of aging infrastructure, cybersecurity risks, and the need to address climate change. His reliance on fossil fuels for energy production also poses challenges in terms of environmental sustainability.

Russia is considered to have a relatively high level of energy security due to its abundant domestic energy resources, especially its large reserves of oil and natural gas, and its strong position as a major energy exporter.
Russia is the world's largest producer of natural gas and one of the world's largest producers of crude oil. It also has significant reserves of coal and nuclear energy infrastructure.

This has given Russia a strong geopolitical position, but also made it vulnerable to geopolitical risks, such as tensions with its neighbors or changes in global energy demand.
Conversely, Russia's energy security also faces aging energy infrastructure, corruption in the energy sector, and the need to reduce greenhouse gas emissions.

China's energy security is a complex issue due to its large and fast-growing economy, its dependence on energy imports, and its commitment to reducing greenhouse gas emissions.
China is the world's largest energy consumer, and its energy demand is expected to continue to grow due to its expanding industrial sector and rising population. However, China's domestic energy resources are limited, and the country relies heavily on energy imports, particularly oil and natural gas.
Also, China's dependence on energy imports makes it vulnerable to geopolitical risks and price fluctuations in the global energy market.

India's energy security is also a complex issue due to its large and rapidly growing economy and dependence on energy imports and was committed as well to promoting renewable energy sources and reducing greenhouse gas emissions.
India is the world's third-largest energy consumer, and its energy demand is expected to continue to grow due to its expanding industrial sector and rising population. However, India's domestic energy resources are limited, and the country relies heavily on energy imports, particularly oil and natural gas.
And as China, the country's dependence on energy imports makes it vulnerable to geopolitical risks and price fluctuations in the global energy market.

Saudi Arabia is considered to have a relatively high level of energy security due to its abundant domestic energy resources, particularly its large reserves of oil and natural gas, and its strong position as a major energy exporter.
Saudi Arabia is one of the world's largest producers of crude oil and a significant producer of natural gas. The country also has significant reserves of coal and has invested heavily in nuclear energy infrastructure.
Conversely, Saudi Arabia's energy security also faces the need to reduce its dependence on oil exports and diversify its economy. Additionally, his reliance on oil exports makes it vulnerable to fluctuations in global energy demand and prices.
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France's energy security can also be considered as a complex issue due to its reliance on energy imports, mainly for oil and natural gas, and its commitment to reducing greenhouse gas emissions and promoting renewable energy sources.

France is the world's second-largest producer of nuclear power, and nuclear energy accounts for a significant portion of the country's energy supply. However, France's domestic energy resources are limited, and the country is heavily dependent on energy imports, particularly for oil and natural gas.

France is also heavily dependent on imported uranium for its nuclear power plants, which makes it vulnerable to geopolitical risks and supply disruptions. France's aging nuclear infrastructure and the high costs of maintaining and decommissioning nuclear power plants pose significant challenges to the country's energy security.

The UK is the world's largest producer of offshore wind energy and has made significant progress in reducing its greenhouse gas emissions. Its energy security can be considered complex because the UK faces several challenges. The domestic energy resources are limited, and the country is heavily dependent on energy imports, particularly for oil and natural gas.

Additionally, the UK's decision to leave the European Union has implications for its energy security, particularly in terms of its access to energy markets and cooperation on energy policy.

South Africa is heavily dependent on coal for electricity generation, with coal-fired power plants accounting for over 80% of the country's electricity production. This reliance on coal has risen concerns over the country's greenhouse gas emissions and air pollution, as well as the environmental impact of coal mining.

South Africa also faces challenges in securing its energy supply due to its reliance on imported oil and gas. His energy security can be considered complex, It has limited domestic reserves of oil and gas, and its aging infrastructure and inadequate investment in energy infrastructure have led to supply disruptions and power outages combined with the country experiencing ongoing challenges around policy uncertainty, corruption, bureaucratic obstacles, and limited investment in renewable energy and energy infrastructure.

Chapter 5: Conclusion

Human civilization requires energy to function, which they gets from energy resources such as fossil fuels, nuclear energy, and renewable energy.

The availability of those resources are always a source of concern and require efficient and effective mechanism such as energy security indicators to mitigate the risk associated with their production and supply.

This paper explored some of the main energy security indicators and their ability to mitigate energy risks at the national and entity levels. we reviewed various indicators and compare the energy security of several industrialized countries based on selected data. The commonly used indicators include energy intensity, energy diversification, and energy efficiency.

The choice of indicators was based on their abilities to prevent energy supply disruptions and price volatility. The limitation faced was the data collected for each indicator and the reliability of the sources.

We identify several indicators that can be used as tools to hedge against energy risks, such as the net energy import dependency ratio, energy intensity, diversity of energy sources in primary energy supply, energy self-sufficiency ratio, and renewable energy share. Each of these indicators can help reduce dependence on imported energy, minimize exposure to risks associated with volatile energy prices, geopolitical tensions, and supply disruptions, and increase energy security. Additionally, to mitigate the energy risk associated with political and regulatory risks such as the current geopolitical tensions faced by Russia, Ukraine Europe and the United stated of America, countries or entities can diversify their energy portfolio, adopt proper risk management strategies, and engage with relevant participants to promote a stable political and regulatory environment for the energy sector.

The next step in mitigating energy risk supply and price volatility could be to explore in depth the alternative source of energy to fossil fuel such as renewable and geothermal energy since almost every country can achieve their production with a suitable level of investment.

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