Chapter

Towards Energy Security for the Twenty-First Century

Collins Ayoo

Abstract

Energy security is a goal that many countries are pursuing to ensure that their economies function without interruption and that their people have access to adequate, reliable and affordable supplies of modern and clean energy. It is a pressing concern because the demand for energy is growing rapidly due to robust economic expansion, population growth, new uses of energy and income growth, and yet the supplies of energy resources required to power these needs are finite and in most cases non-renewable. Furthermore, the production, transportation and utilization of energy are a major source of greenhouse gases that cause global warming and climate change. This chapter examines the multidimensional nature of energy security, presents some indicators that can be used to assess changes in energy security and outlines a range of policy measures that can be used to improve energy security. These include more investments in energy production and transmission; promotion of energy efficiency in various end-use sectors; modernization of the grid to enable the integration of renewables such as wind, solar and geothermal energy into the energy system; undertaking reforms in energy markets to attract private sector investment in energy production, increase competition, reduce wastage and lower costs to energy users and fostering greater international collaboration on energy issues and regional energy trade.

Keywords: energy security, energy security indicators, energy efficiency, renewable energy, energy demand, energy market reforms

1. Introduction

Energy is a critical resource that all economies require to produce goods and services and to enhance human, social, and economic wellbeing [1–4]. It is needed by various industries as an input into the production of goods and services, for transportation, and by households for heating, cooking, lighting and powering domestic appliances. Empirical studies show that energy consumption is positively correlated with indices of economic growth and wellbeing [3]. This is why the provision of energy to most of the world's population has been identified as a criterion for assessing progress towards sustainable development. Both developed and developing countries, however, face a myriad of energy challenges that include inadequate and unsuitable supplies of energy sources, energy supply uncertainties, high and fluctuating prices of energy, and environmental pollution and degradation as a result of the production, distribution, and use of energy. For countries that rely heavily on energy imports from politically unstable regions, additional risks stem from the threats of disruption to energy supplies and the destabilizing effects of such disruptions to their economies and energy markets [5, 6]. Examples of such disruption include the 1973 and 1979 oil crises, the disruption of world oil supplies during the Persian Gulf wars, and the disruption of natural gas supplies to Ukraine in 2014 due to disagreements with Russia [7]. More recently concerns have emerged from energy supply and storage infrastructure due to natural disasters and terrorism. For countries such as the United States, these challenges are intricately linked to their national security. For poor countries, these challenges have undermined their prospects of economic development and constrained their efforts to alleviate poverty and improve the standards of living of their peoples. They have also had an adverse impact on the balance of payments. Addressing these challenges has therefore increasingly become the centrepiece of the energy policies of many countries where the issue is being framed as one of enhancing energy security. This chapter examines energy security with a focus on its nature and meaning, its multiple dimensions, the indicators currently being used to measure energy security, and some policy measures that can be used to enhance energy security.

2. Meaning of energy security

A clear conceptualization of energy security is essential for an efficient and effective pursuit of this policy goal. The literature on energy security is however characterized by widely differing and sometimes inconsistent definitions of the concept. This is partly because various authors on the subject have tended to focus on different sources of risk and conducted studies that differ in the scope of the impacts of the various risks. The International Energy Agency (IEA) that was formed in the 1970s to coordinate a robust response to disruptions to oil supplies defines energy security as the uninterrupted availability of energy sources at an affordable price. Bohi and Toman [8, 9] define energy insecurity as the loss of welfare that may occur as a result of a change in the price or availability of energy. Cherp and Jewell [10] assert that energy security is an instance of security in general and define energy security as "low vulnerability of vital energy systems". Winzer [11] notes that energy security is commonly defined by incorporating the context. Thus, in the United States, the focus of energy security has traditionally been on the reduction of vulnerability to political extortion following the economic hardships experienced in the aftermath of the oil embargo by the Organization of Petroleum Exporting Countries (OPEC) in the 1970s. This is also the reason why policy makers in the United States strongly support the goals of energy independence and raising the shares of renewable energy. Winzer [11] further notes that in several developing countries, the goal of energy security has been to protect the poor against commodity price volatility. He defines energy security as continuity of energy supplies relative to energy demand. According to Andrews [12] and Jun et al. [13], energy security means assuring adequate, reliable supplies of energy at reasonable prices and in ways that do not jeopardize major national values and objectives. Intharak et al. [14] define energy security as the ability of an economy to guarantee the availability of energy supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect economic performance. Their definition thus embodies three fundamental aspects, namely, physical energy security which is the availability and accessibility of energy supply sources; economic energy security which is the affordability of resource acquisition and energy infrastructure development; and, environmental sustainability which entails using energy resources in ways that meet the needs of the present without compromising the ability of future generations to meet their own needs [15]. According to

Grubb et al. [16] and Kruyt et al. [17], security of supply is a system's ability to provide a flow of energy to meet demand in an economy in a manner and price that does not disrupt the course of the economy. They further point out that non-secure energy systems are characterized by sharp energy price increases, reduction in quality, sudden supply interruptions, and long-term disruptions of supply. Sovacool [18–21], Sovacool and Brown [22], Sovacool and Mukherjee [23], Sovacool et al. [24], Brown and Sovacool [25], and Badea et al. [26] define energy security as equitably providing available, affordable, reliable, efficient, and environmentally benign energy services to end users. Brown et al. [27] opine that energy security has to do with questions of reliable energy supplies, regional concentration of energy resources, and the implications of strategic withholding of energy. They point out specific aspects of energy security such as electricity reliability, natural gas and petroleum security, and the vulnerability of the entire energy supply chain. They also maintain that robust global coordination of responses to energy supply shock is critical to energy security. According to APERC [28], energy security consists of 4A's namely, availability, accessibility, acceptability, and affordability.

Although the definitions of energy security provided above are not exhaustive, they all illustrate the importance of energy security, its multi-dimensional nature, and why many countries regard it as a policy priority. In the short-term, energy security concerns focus on the ability of the energy system to react promptly to sudden changes in the supply–demand balance. In the long-term, energy security concerns have to do with timely investments in energy supply in line with economic developments and environmental needs. At the multilateral and global levels, energy security has continued to receive increasing attention as evidenced by Sustainable Development Goal 7 of the United Nations that requires countries to ensure access to affordable, reliable, sustainable, and modern energy for all.

3. Indicators of energy security

Several indicators have been proposed for assessing the energy security risks that various countries face, how the energy security situations have been changing over time, and how energy security is impacted by the energy policies of these countries. Estimates of these indicators are valuable in developing energy security strategies that take into account countries' energy resource endowments, market conditions, vulnerabilities to energy supply shocks, and technological progress. In what follows I present some energy security indicators, explain their use in assessing energy security, and provide energy security metrics for selected countries.

3.1 Energy reserves

Energy reserves refer to the estimated quantity of energy sources (e.g. coal, gas, or oil) known to exist with reasonable certainty, and which can be recovered with presently available technology at an economically viable cost. A country's energy resources and the extent to which they are developed is an important determinant of energy security. In general, countries with vast energy resources are more energy secure compared to those with meagre energy resources. Over time, however, changes can occur that alter a country's energy resources and thus improve or worsen its energy security. For example, the discovery of vast oil and gas resources in the North Sea had a significant impact on Norway's economy and energy security and made Norway a rich oil-exporting country [29]. This is also the case with countries which have recently discovered new energy reserves. **Table 1** presents

	1980	1990	2000	2010	2017
North America	123.3	125.4	232.1	221.5	226.1
South and Central America	26.9	71.5	97.9	325.2	330.1
CIS	67.0	58.4	120.5	144.5	144.9
Europe	16.6	17.5	20.6	13.4	13.4
Middle East	362.4	659.6	696.7	765.9	807.7
Africa	53.4	58.7	93.0	124.5	126.5
Asia Pacific	33.9	36.3	40.1	48.0	48.0
World	**683.5**	**1027.5**	**1300.9**	**1643.1**	**1696.6**

Table 1.
Proved oil reserves in thousand million barrels 1980–2017 [30].

	1980	1990	2000	2010	2017
North America	9.6	9.2	7.2	10.5	10.8
South and Central America	2.8	5.5	7.3	8.1	8.2
CIS	20.5	34.9	40.3	50.0	59.2
Europe	4.2	5.2	4.7	4.4	3.0
Middle East	24.2	37.2	58.3	78.2	79.1
Africa	5.7	9.0	11.9	14.0	13.8
Asia Pacific	4.5	9.0	11.1	14.9	19.3
World	**71.6**	**109.3**	**140.9**	**180.1**	**193.5**

Table 2.
Proved natural gas reserves in trillions of cubic metres [30].

estimates for the proved oil reserves for various geographic regions for selected years from 1980 to 2017. Estimates for natural gas are presented in **Table 2**.

Table 1 shows that the Middle East has the greatest quantity of proven oil reserves followed by North America. Although these two regions account for more than 50% of the world's total proven oil reserves, this fact alone own does not confer on the regions the greatest energy security. Assessing oil security requires a consideration of additional factors such as oil production and consumption and how these are evolving over time. **Table 1** also shows that over time, with the exception of Europe, several regions of the world have reported an increase in their proven oil reserves thus suggesting an improvement in oil security. The case of the United States is particularly significant given that it has in recent years considerably expanded its production and reduced its dependence on oil imports. This has been possible through the shale revolution and also through changes to regulations to permit the drilling and extraction of oil in previously proscribed areas.

Table 2 shows that the Middle East has the largest proven natural gas reserves followed by the CIS. Like the case of oil, most regions of the world have reported an increase in proven natural gas reserves from 1980 to 2017. The exception is Europe whose proven natural gas reserves have declined. The proven reserves of oil and natural gas are a good indicator of the existence or otherwise of potential that can be developed to improve the energy security.

Table 3 shows the proven reserves of coal and the reserve-to-production ratios (R/P ratios) for the various regions at the end of 2017. R/P ratios estimate the time period remaining for the different regions to exhaust their known coal stocks given the current rates of extraction, assuming no changes in existing stocks,

	End of 2017	R/P ratio
North America	258,709	335
South & Central America	14,016	141
CIS	223,228	397
Europe	100,405	159
Middle East and Africa	14,420	53
Asia Pacific	424,234	79
World	**1,035,012**	**134**

Table 3.
Proved coal reserves in millions of tonnes and reserves to production ratio [30].

technologies, or other policies. At the world level, the existing coal reserves can last for about 134 years. The existing coal stocks can last for periods ranging from 53 years for the Middle East and Africa to about 335 years for North America. Based on these results it can be inferred that in the short to medium term, there will be continued energy security with respect to coal availability and utilization. Although concerted efforts are currently being made to reduce the use of coal as part of measures to mitigate climate change, the use of coal will continue to be significant for certain regions of the world. It however implies that coal will play an increasingly smaller role in energy security in the coming years. This could change if significant progress in the carbon capture and storage technologies results in greater use of coal.

3.2 Energy production and consumption

Being the predominant source of energy in most of the world, the production and consumption of oil can serve as a valuable indicator of energy security.

		1980	1990	2000	2010	2017
North America	Production	670.7	654.5	642.5	638.6	916.8
	Consumption	928.4	923.2	1060.6	1040.5	1056.4
South and Central America	Production	194.7	234.0	345.0	378.5	368.3
	Consumption	170.9	176.2	235.1	299.4	317.0
Europe	Production	143.4	217.9	332.5	196.7	162.6
	Consumption	779.2	729.4	762.5	734.2	708.3
CIS	Production	603.2	570.3	396.4	663.1	699.6
	Consumption	421.5	399.1	169.1	178.6	196.3
Middle East	Production	934.0	837.4	1146.9	1220.0	1481.1
	Consumption	93.7	166.5	239.0	356.9	404.4
Africa	Production	300.5	317.0	371.6	481.5	383.3
	Consumption	69.6	95.6	118.4	164.4	189.3
Asia Pacific	Production	244.8	325.9	381.3	403.0	375.5
	Consumption	515.4	664.2	998.3	1302.1	1598.0
World	Production	**3091.3**	**3157.0**	**3616.2**	**3981.4**	**4387.1**
	Consumption	**2978.7**	**3154.1**	**3583.1**	**4076.0**	**4469.7**

Table 4.
Oil production and consumption in millions of tonnes from 1980 to 2017 [30].

The production and consumption of oil for various regions from 1980 to 2017 is shown in **Table 4** and depicted in **Figures 1–8**. At the global scale, both the production and consumption of oil have been growing over time with the oil production consistently matching the oil consumption. This implies that the world has the potential to be energy secure if robust mechanisms are implemented to facilitate the flow of oil from regions with oil surpluses to those with oil deficits. For North America, Europe and Asia Pacific, the oil consumption has consistently exceeded the oil production while for Africa, the Middle East, the CIS, and Central and South America, the oil production has over time been greater than the oil consumption. The United States has for several decades been the largest consumer of oil in the world and has relied considerably on oil imports to bridge the gap between its production and consumption of oil. This has been a major policy concern in the US

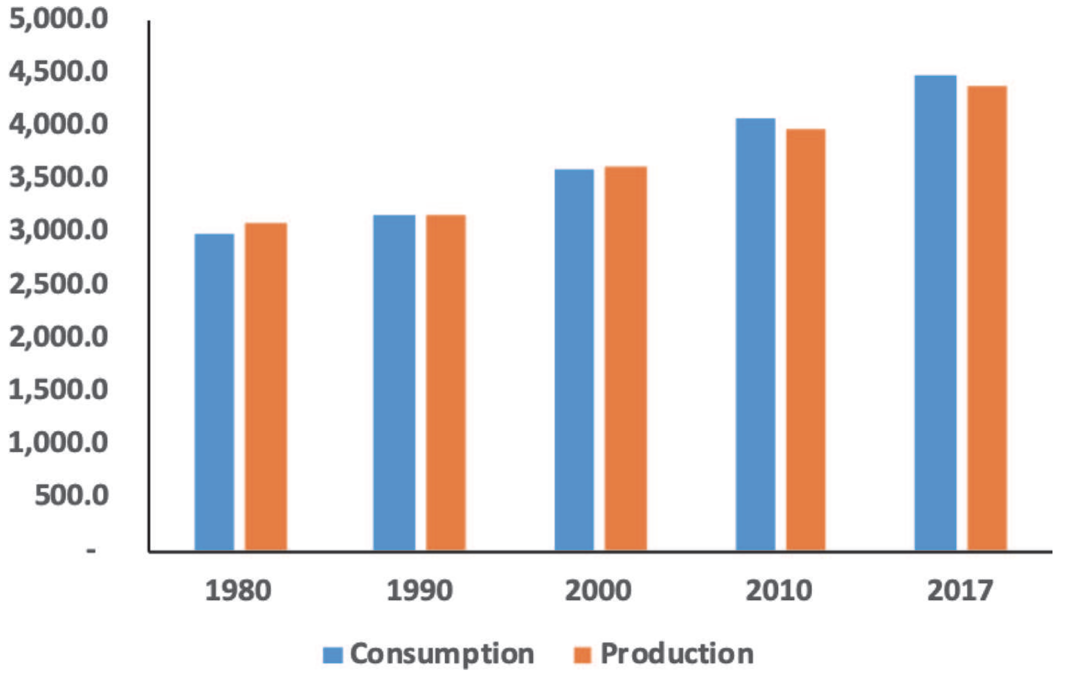

Figure 1.
Oil production and consumption for the world in millions of tonnes from 1980 to 2017 [30].

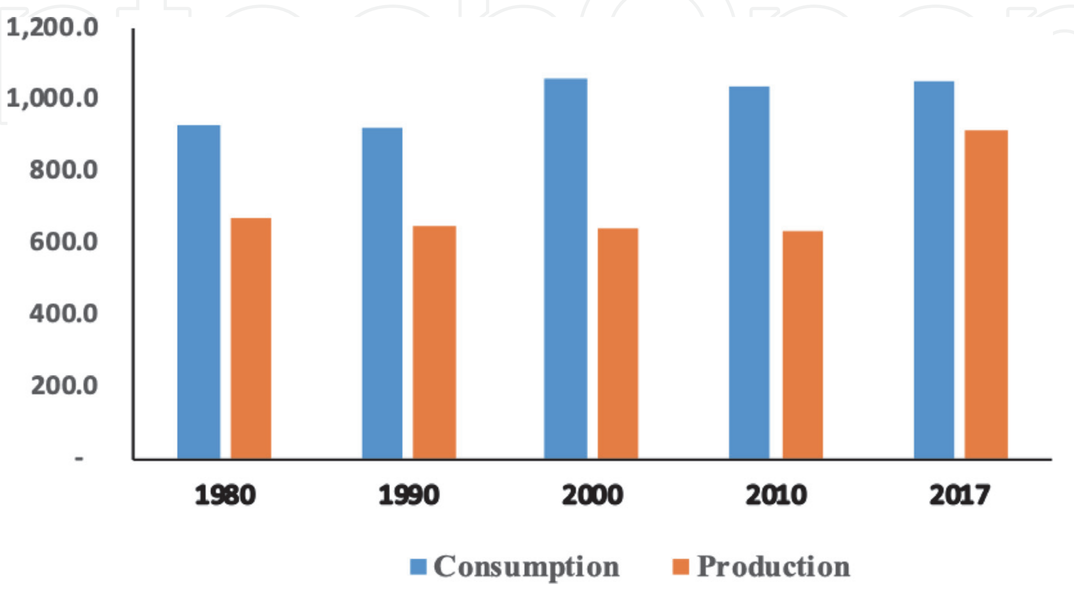

Figure 2.
Oil production and consumption for North America in millions of tonnes from 1980 to 2017 [30].

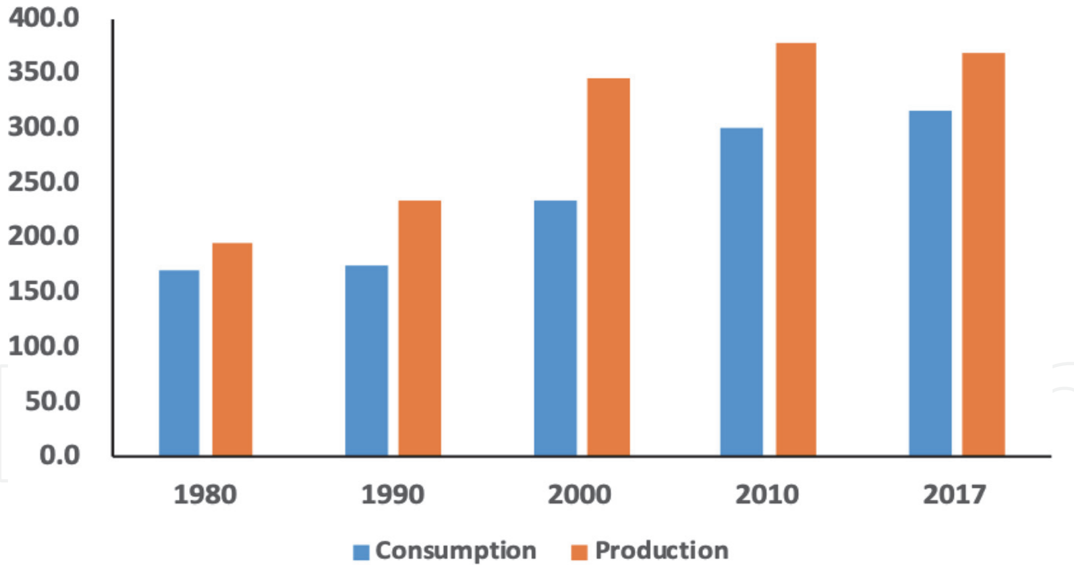

Figure 3.
Oil production and consumption for South and Central America in millions of tonnes from 1980 to 2017 [30].

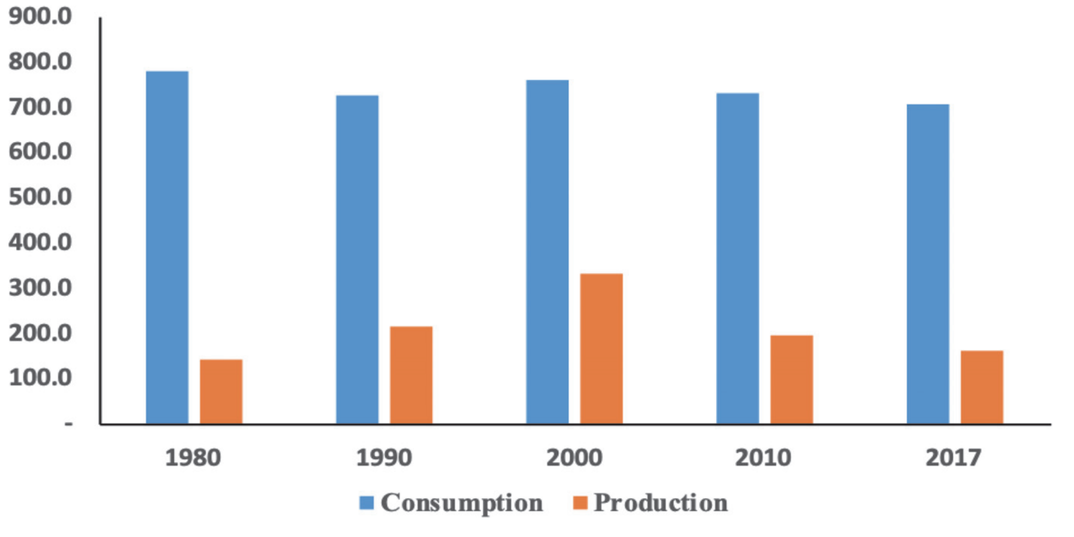

Figure 4.
Oil production and consumption for Europe in millions of tonnes from 1980 to 2017 [30].

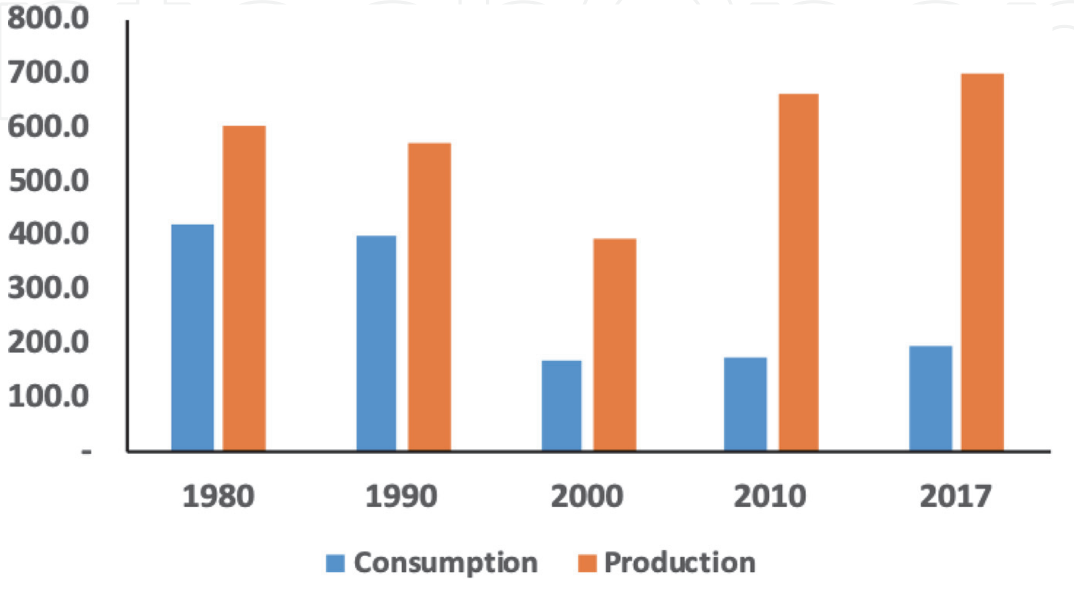

Figure 5.
Oil production and consumption for CIS in millions of tonnes from 1980 to 2017 [30].

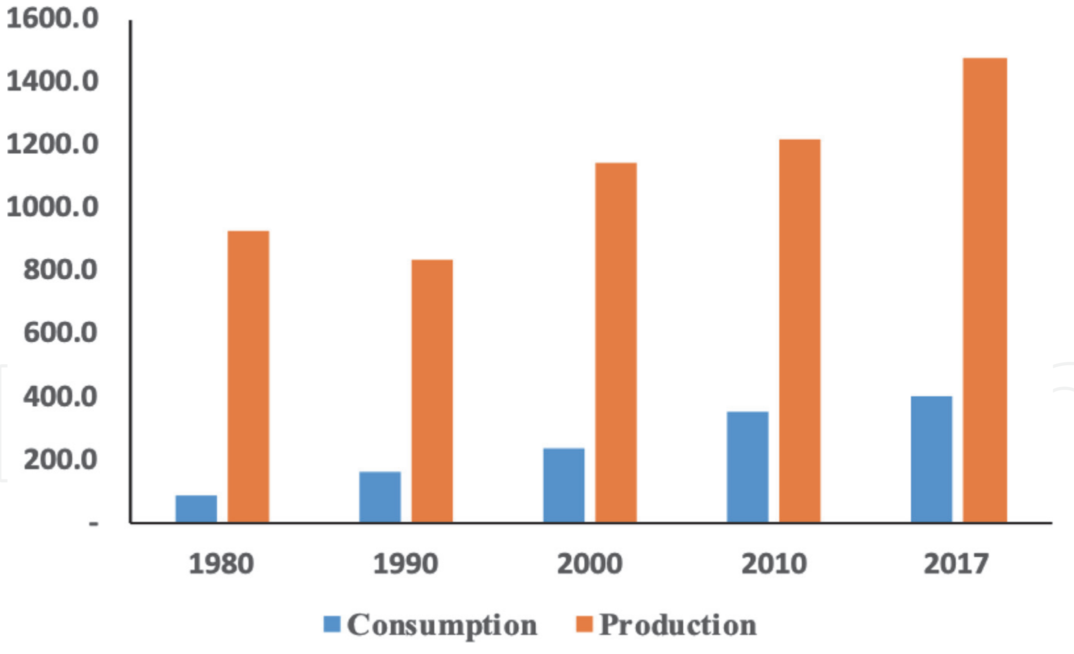

Figure 6.
Oil production and consumption for the Middle East in millions of tonnes from 1980 to 2017 [30].

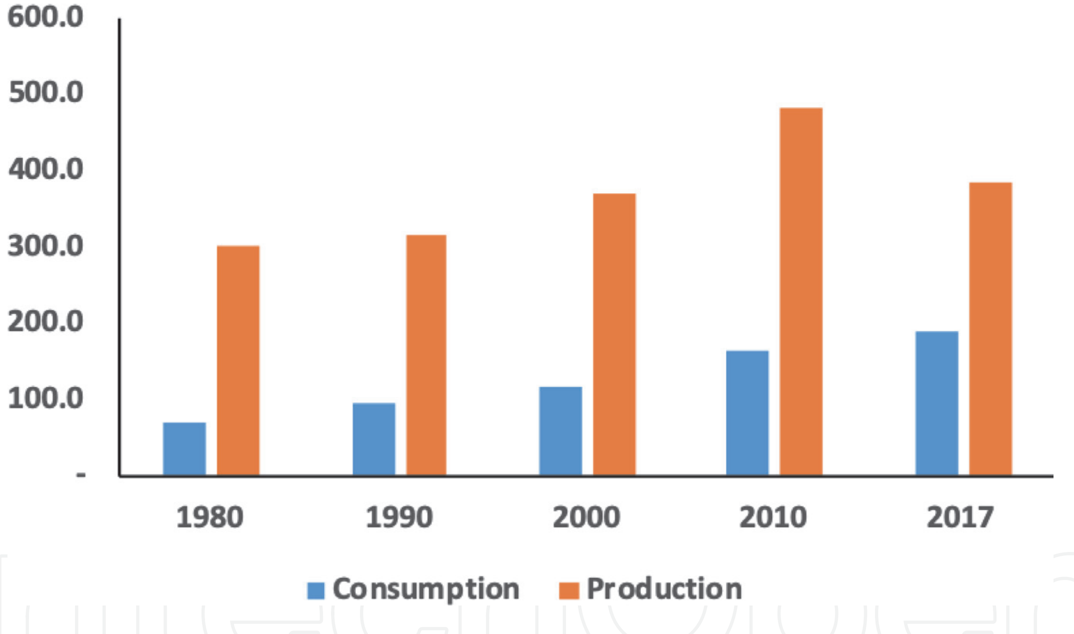

Figure 7.
Oil production and consumption for Africa in millions of tonnes from 1980 to 2017 [30].

and partly explains the country's preoccupation with the goal of energy independence since the oil crises of the 1970s.

The data in **Table 4** also shows that the Middle East and the CIS have had the greatest oil surpluses while Europe has had the greatest oil deficit. From this broad picture that is based on aggregated regional data, we can infer that relative to other regions, Europe and Asia Pacific have the greatest oil insecurity, while the Middle East, Africa, and the CIS are the least oil insecure. In the recent past, the oil consumption in the Asia Pacific has grown rapidly due to its high population and economic growth rates.

Natural gas constitutes a significant share of the energy mix of several countries and contributes critically to their energy security. It is used for heating buildings and water, to cook, to operate refrigeration and cooling equipment, to dry clothes, to provide outdoor lighting, as a fuel in combined heat and power systems, as a fuel to operate compressors that move natural gas through pipelines, to generate electricity, and as a vehicle fuel in the form of compressed natural gas and liquified natural gas. Natural gas is also used as a raw material to produce chemicals, fertilizers and hydrogen.

Table 5 presents data on the production and consumption of natural gas in various world regions from 1970 to 2017. **Figure 9** depicts the global production and consumption of natural gas over the same period. Overall, both the production and

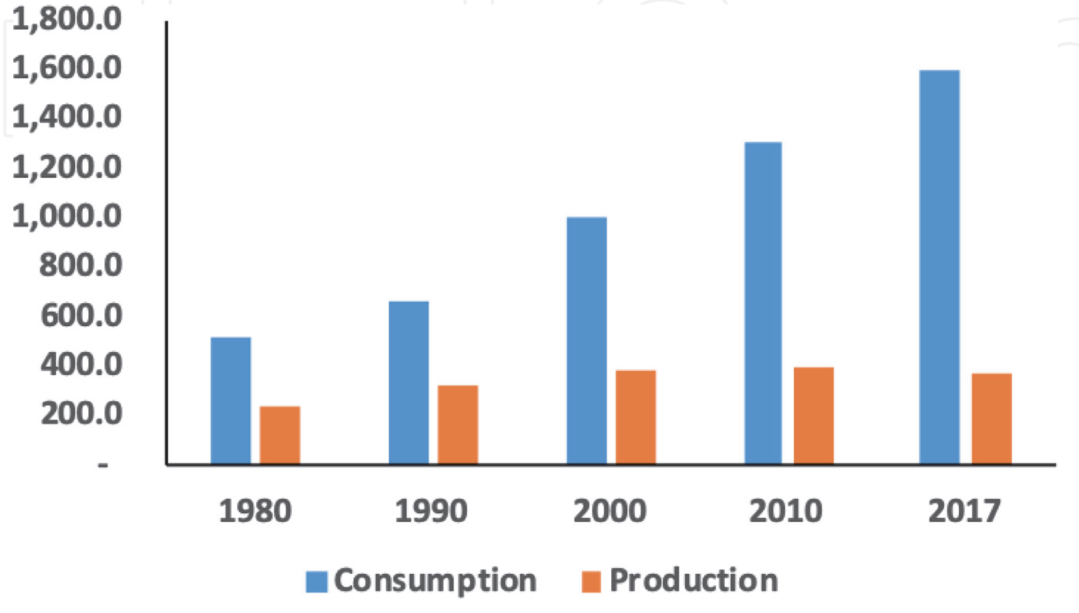

Figure 8.
Oil production and consumption for Asia Pacific in millions of tonnes from 1980 to 2017 [30].

		1970	1980	1990	2000	2010	2017
North America	Production	636.5	621.4	613.2	728.3	775.9	951.5
	Consumption	619.5	605.8	607.6	753.5	803.0	942.8
South & Central America	Production	18.7	35.3	60.3	103.1	163.8	179.0
	Consumption	18.8	36.1	59.6	97.8	150.1	173.4
Europe	Production	104.5	229.5	215.5	293.5	289.5	241.9
	Consumption	108.5	280.7	360.8	484.0	567.7	531.7
CIS	Production	187.5	412.2	764.1	661.6	755.9	815.5
	Consumption	189.5	377.1	632.1	527.2	588.7	574.6
Middle East	Production	10.5	34.4	101.8	206.5	481.6	659.9
	Consumption	9.4	31.9	96.7	185.6	385.6	536.5
Africa	Production	3.0	24.8	72.2	135.1	206.1	225.0
	Consumption	1.6	18.7	39.9	55.7	102.5	141.8
Asia Pacific	Production	15.1	71.9	149.3	277.4	496.5	607.5
	Consumption	14.2	73.6	152.0	298.2	578.3	769.6
World	**Production**	**975.8**	**1429.6**	**1976.3**	**2405.5**	**3169.3**	**3680.4**
	Consumption	**961.4**	**1423.8**	**1948.7**	**2402.0**	**3175.9**	**3670.4**

Table 5.
Natural gas production and consumption in billions of cubic metres from 1970 to 2017 [30].

consumption of natural gas have been increasing over time with the production increasing to match the consumption.

According to the data in **Table 5** and **Figures 10** and **11**, North America, the CIS, the Middle East and Africa produced at least as much natural gas as they consumed in 2017. For the Middle East and the CIS, the natural gas production was significantly higher than the consumption making these regions important global exporters of natural gas. For Europe and Asia Pacific, the production of natural gas has tended to be significantly less than the consumption necessitating the heavy reliance of these regions on large natural gas imports to meet their demands. For the Asia Pacific region, the consumption of natural gas has in recent years been rising rapidly due to robust economic growth and the high population in the region. The

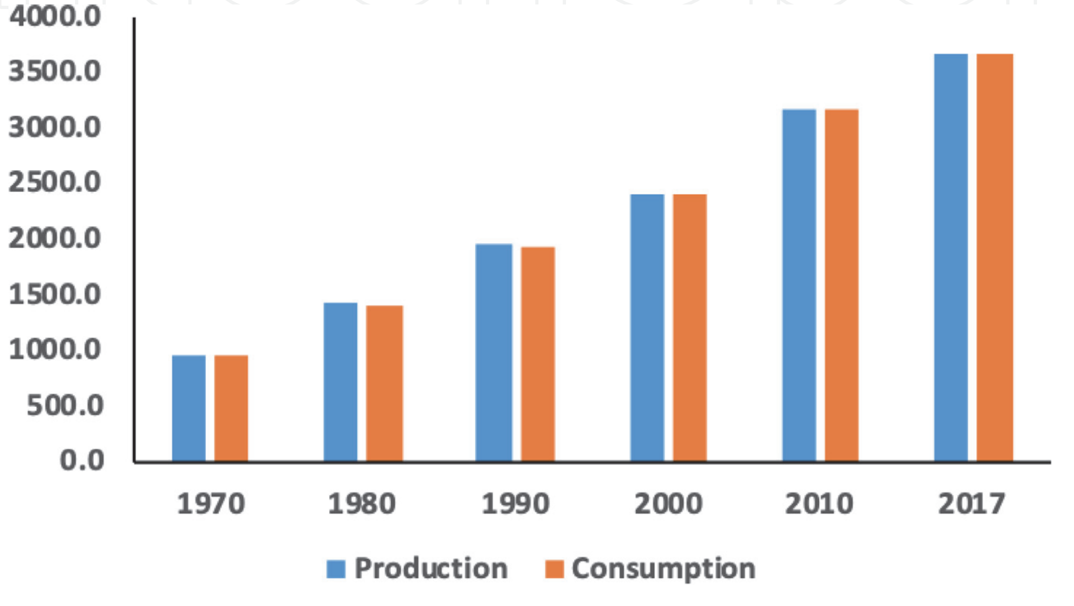

Figure 9.
Global natural gas production and consumption in billions of cubic metres from 1970 to 2017 [30].

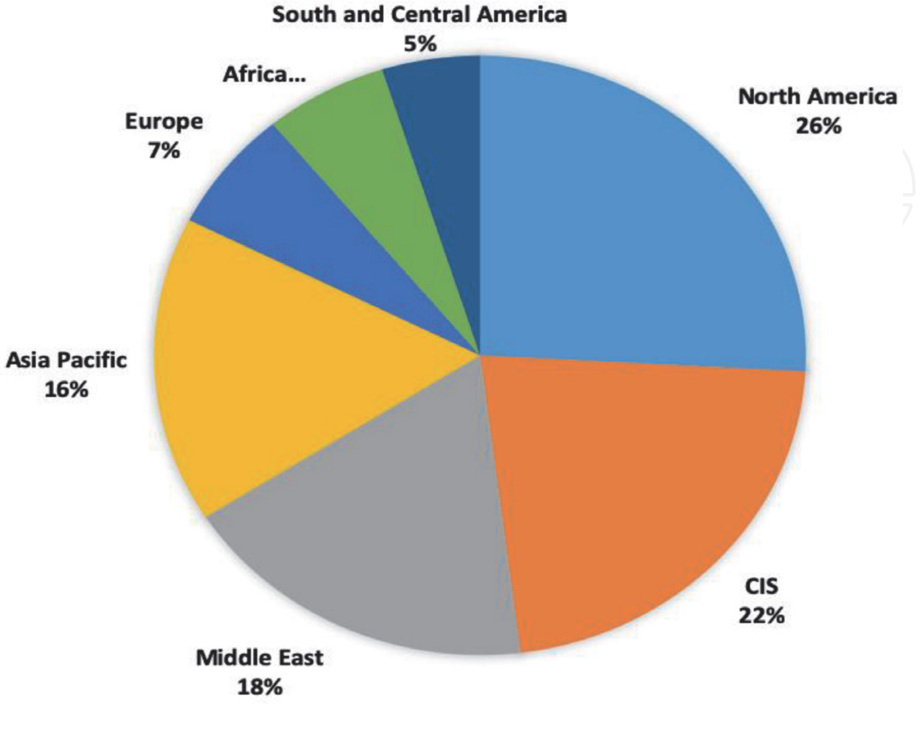

Figure 10.
Regional shares of natural gas production in 2017 [30].

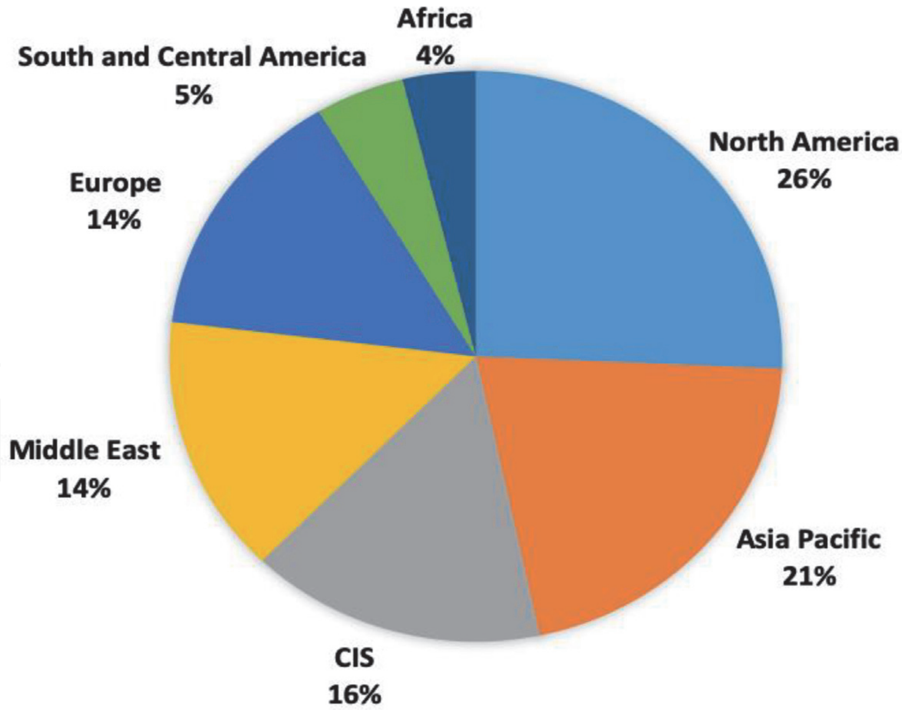

Figure 11.
Regional shares of natural gas consumption in 2017 [30].

situation in Europe is considerably tighter as evidenced by the fact that in 2017 the production of natural gas was less than half the amount consumed in the region thus implying a high dependence on natural gas imports. In the foreseeable future, natural gas security in Europe and the Asia Pacific region will depend on stable, well-integrated efficient natural gas markets that can ensure adequate, reliable and affordable supplies.

The shortage of natural gas in China in the winter of 2017 is a recent example of how the demand and supply of natural gas can impact energy security. The primary cause of the shortage was China's decision to curb reliance on dirty coal so as to reduce urban air pollution and improve the overall quality of the environment. This shift in policy triggered an increase in the demand for natural gas and a rise in its price not only to consumers in China but also for other natural gas importers [31, 32]. The shortage of natural gas in China and the spike in its price occurred despite a glut in global supply and was due to infrastructure and logistical constraints. Achieving natural gas security therefore requires not only initiatives aimed at boosting natural gas production, but also complementary measures such as increased investments in distribution infrastructure and improving LNG shipping capacity.

Electricity is critically important to most economies around the world and its role is expected to increase in the future as countries pursue the goal of decarbonizing their power sectors. Electricity is also important in efforts to eliminate poverty and transform the world into a safe, equitable and environmentally sustainable place [33]. Today, however, many countries are facing massive challenges in electricity security due to rapidly increasing demand and supply constraints. **Table 6** shows the production and consumption of electricity for various regions from 1990 to 2017. With the exception of the CIS where the electricity production fell by about 7% between 1990 and 2017, in all other regions electricity production increased with the greatest percentage increase being in Asia (400%) and the Middle East (387.7%).

The consumption of electricity has been increasing rapidly in most part of the world with the main drivers being industrial and economic growth, and population

		1990	2000	2010	2017	% Change
North America	Production	3701	4658	4982	4963	34.1
	Consumption	3146	4093	4415	4379	39.2
Latin America	Production	605	982	1375	1590	162.8
	Consumption	506	788	1129	1312	159.3
Europe	Production	2900	3438	3865	3886	34.0
	Consumption	2516	2952	3377	3377	34.2
CIS	Production	1676	1250	1483	1566	−6.6
	Consumption	1417	1000	1203	1257	−11.3
Middle East	Production	244	472	892	1190	387.7
	Consumption	213	400	742	977	358.7
Africa	Production	319	446	675	818	156.4
	Consumption	263	379	554	663	152.1
Asia	Production	2259	4024	7983	11,274	399.1
	Consumption	1923	3369	6869	9777	408.4
Pacific	Production	190	253	302	304	60.0
	Consumption	165	218	265	273	65.5

Table 6.
Electricity production and consumption in terawatt Hours (TWH) from 1970 to 2017 [30].

increase. **Figure 12** depicts the consumption of electricity for the various regions in 1990 and 2017. It is evident from **Figure 12** that the greatest absolute increase in electricity consumption over this period occurred in Asia where electricity consumption increased by 408.4% from 1923 TWH to 9777 TWH. Most of the growth in electricity consumption in Asia occurred in China, India, and Japan. Over the 1990–2017 period, the electricity consumption in China increased from 534 TWH to 5683 TWH; that in India increased from 215 TWH to 1156 TWH; and, that in Japan increased from 781 TWH to 1019 TWH. These increases in electricity consumption occurred despite strong energy efficiency improvements.

The electricity production and consumption data for the various regions for 2017 that is plotted in **Figure 13**, shows that although both electricity production and consumption have been increasing over time, the production of electricity exceeded its consumption. Therefore, the inference can be made that at the regional level, potential exists for achieving electricity security in the short to medium term. The broad picture presented in **Figure 13** masks the electricity supply and demand conditions in specific countries and how the electricity is produced and consumed in those countries. It also masks the fact that due to grid and storage losses, not all of the electricity produced is available for consumption.

3.3 Energy trade balances

At particular times, specific countries or regions often have imbalances in their demand and supply of energy that are met through imports and exports. Whether a country is a net importer or exporter of energy is indicated by their energy trade balance that is computed as the difference between energy imports and exports. Countries that are net energy exporters have negative energy trade balances while net energy importers have positive energy trade balances. Based on energy trade

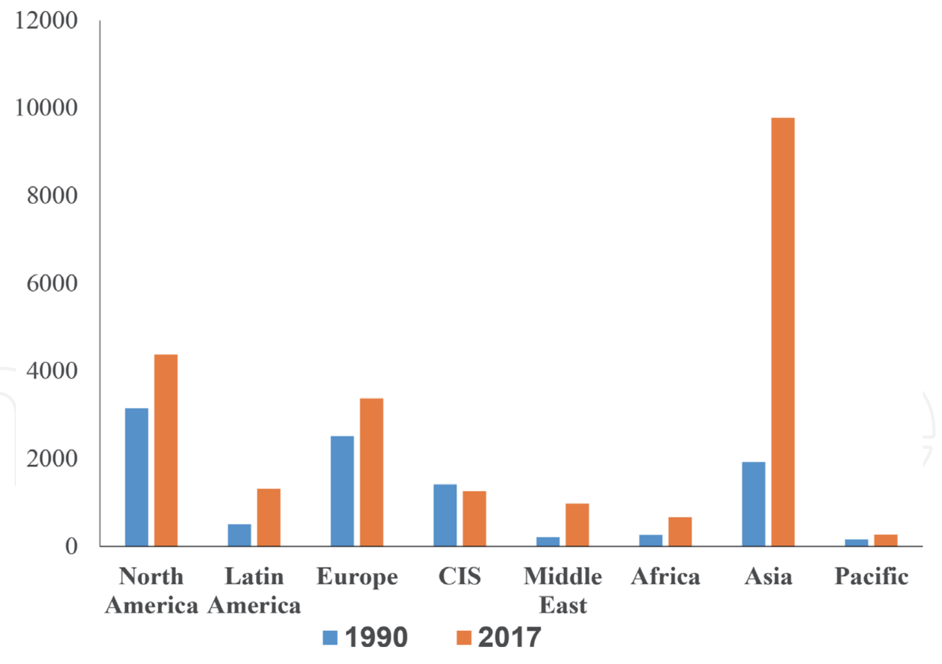

Figure 12.
Electricity consumption in terawatt hours (TWH) for 1990 and 2017 [30].

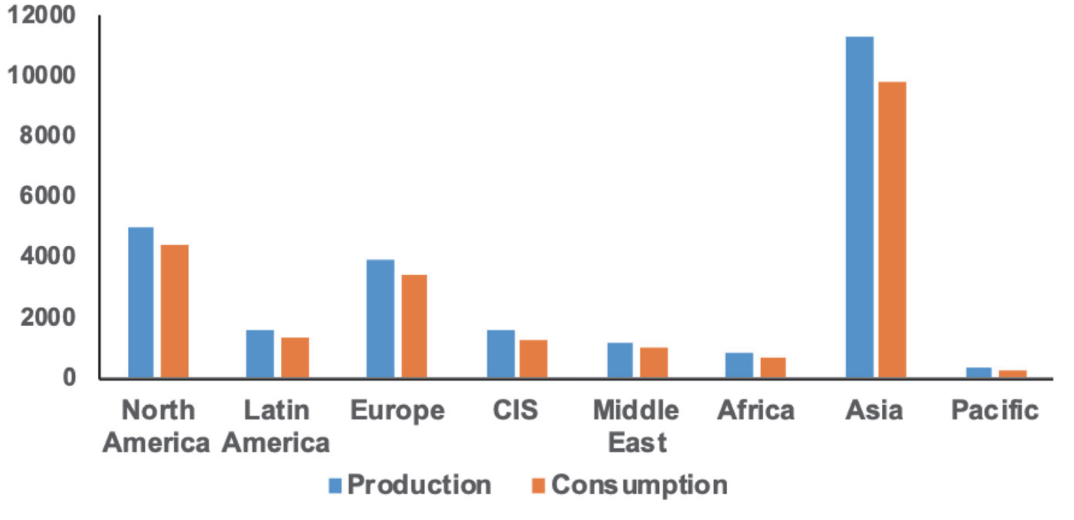

Figure 13.
Electricity production and consumption in terawatt hours (TWH) for 2017 [30].

balances, it can be inferred that regions with positive energy trade balances are more energy insecure compared to those with negative energy trade balances. **Figure 14** depicts the energy trade balances for various regions for 2017 and shows that the largest energy net importers were Asia and Europe and the largest net exporters were the Middle East and the CIS. Europe's energy security situation is precarious because of dwindling energy supplies that have necessitated increasing reliance on energy imports. Importation of less expensive energy into Europe from regions such as the Middle East is a more attractive option compared to more costly efforts to develop the region's own energy resources. As producers of large quantities of cheap energy, the Middle East and the CIS will continue to play a significant role in the global energy scene in the short to medium term. It is worth noting that several major changes are currently occurring in global energy markets and that these changes will have profound implications on energy security in the coming years. An example of such a change is the increase in energy production in the United States that has changed the country's status from a net energy importer to a net energy exporter.

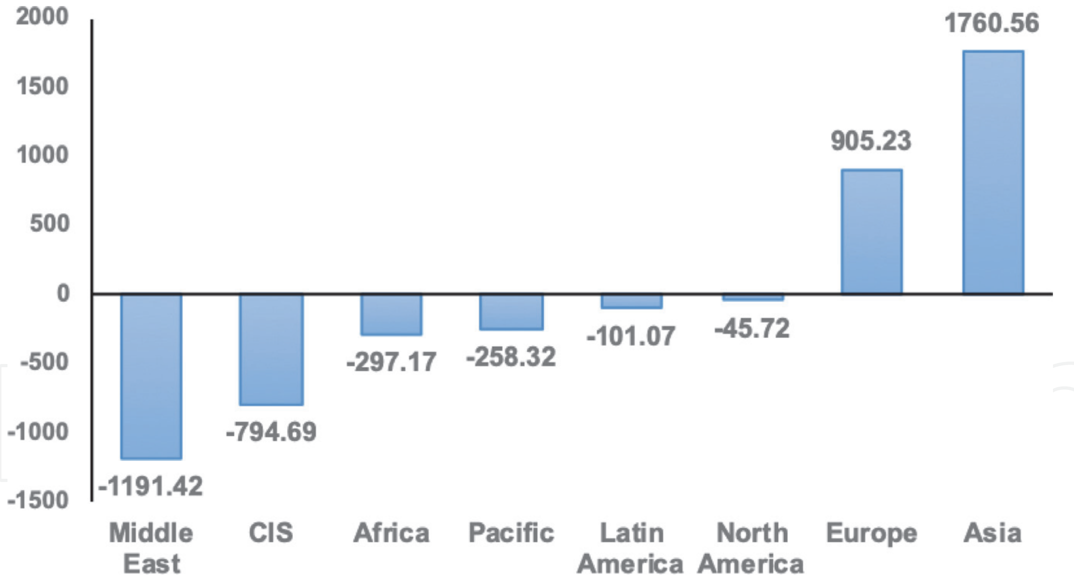

Figure 14.
Energy trade balance in megatons of oil equivalent (Mtoe) in 2017 [30].

3.4 Energy prices

In general, energy prices are determined by the supply and demand conditions in energy markets and also by the policies and regulations such as taxes and subsidies that governments may make to regulate these markets and achieve particular outcomes. Energy prices are an important indicator of energy security to the extent that they embody information about energy scarcity and energy affordability and also play a central role in energy investment decisions. The crude oil prices from 1970 to 2017 are depicted in **Figure 15**. Although the crude oil prices have fluctuated widely over this period, the general trend has been upward. In 1973 the world oil market was significantly impacted by the oil embargo by the Organization of Petroleum Exporting Arab Countries (OPEC) that drastically reduced the supply of oil at a time when the demand for oil was increasing. This action resulted in the price of oil rising from US$ 3 to US$ 12 globally. World oil supplies were again adversely affected in 1979 in the aftermath of the Iranian Revolution and oil prices

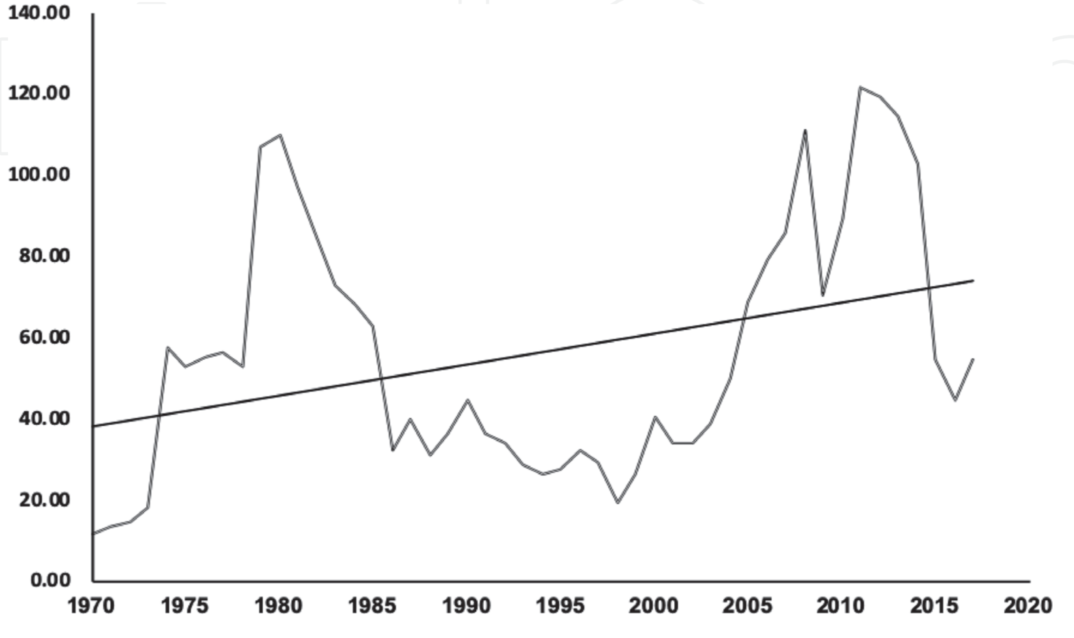

Figure 15.
Crude oil prices from 1970 to 2017 in $ 2017 [30].

increased rapidly from $13 per barrel in mid-1979 to about $34 per barrel in mid-1980. Both these oil shocks threated the energy security of oil-importing countries, reduced economic activity, and increased inflation.

In several developing countries, a significant fraction of the population cannot access modern energy due to the high energy prices. In Kenya, for example, where the majority of the population use Kerosene for cooking and lighting, the price of kerosene has recently risen rapidly thus inducing low income households to reduce their use of kerosene and shift towards wood fuel. Although liquefied natural gas is available, its high price has limited its use to medium and high-income households. Further energy price increases can be expected as energy markets are increasingly deregulated and energy subsidies eliminated. To the extent that these measures reduce energy affordability, they have an adverse effect on household energy security. This brief discussion of energy prices underscores the fact that a strong correlation exists between energy prices and energy security and that, in general, energy security will be compromised when energy prices are rising rapidly. These broad conclusions can be extended to other energy sources such as electricity and natural gas.

3.5 Energy diversity

All else equal, economies that depend on a limited portfolio of non-renewable energy sources are less energy secure compared to those endowed with an abundance of diverse energy supplies [34]. Energy systems that are diverse are more resilient and adaptable to shocks in energy supplies. The Russian-Ukrainian gas crisis is an example of the vulnerability that can result from dependence on a single supplier of energy. In January 2006 following disagreements about the price of natural gas and the cost of transit, Russia cut off all gas supplies passing through Ukraine thus adversely affecting several European nations. In January 2009, disagreements about natural gas price again resulted in the disruption of natural gas supplies from Russia to 18 European nations. The severity of this threat to Europe's energy security stems from the fact that Russia provides about 25% of the natural gas consumed in the European Union and that approximately 80% of natural gas exports from Russia to the European Union are through pipelines across Ukraine. The Southern Gas Corridor (SGC) was started as a response to the overdependence of many countries in Central and South East Europe on Russia to meet most or all of their natural gas requirements. The overarching goal of the SGC was to enhance EU's energy security by diversifying the routes and sources of gas supplies to the EU [35, 36]. This strategic objective has been achieved through the construction of a system of pipelines that can bring natural gas from the Caspian Basin, Central Asia, the Middle East, and the Eastern Mediterranean Basin into Europe thus reducing the dependence on Russian natural gas supplies [35].

The contribution of diversity to energy security also applies to other domains such as transportation fuels and the generation of electricity. In the transportation sector, the fuels that are mostly used are gasoline and diesel due to their high energy content. Some measures that are currently being undertaken to enhance transportation energy security are developing and promoting the use of alternative fuels such as ethanol, natural gas, biodiesel, hydrogen, propane, methanol and electricity (as in the case of battery-powered electric and fuel-cell vehicles). In addition to reducing dependence on fossil fuels, the use of these alternative fuels has been cited as having the potential to drastically lower the emissions of greenhouse gases and thus mitigate the risk climate change. There are however several controversies associated with the increased use of alternative transportation fuels as a strategy for diversifying the energy mix. For example, the simulation model developed by

Chen et al. [37] shows that although promoting greater production of food-based biofuels reduces overall fossil fuel use, it leads to a marginal reduction in the global greenhouse emissions, and a large increase in food prices. Flynn [38] noted that the adoption of compressed natural gas as an alternative transportation fuel in Canada and the United States had been slow and below the critical level which would enable suppliers to survive in a competitive market. The reasons for this outcome include the high cost of hybrid cars relative to conventional cars, the lack of infrastructure to support converted vehicles, lack of refuelling facilities, and the failure of existing refuelling stations to achieve profitability.

Diversifying electric power generation is an area that several countries are increasingly focusing on to enhance their overall energy security. It is driven by the increase in the demand for electricity due to factors such as population growth, greater use of electrical appliances and equipment, and the need reduce emissions of greenhouse gases. In a country such as the United States, the main energy sources for electric power generation are coal, natural gas, nuclear power and hydro. The amounts of electricity produced from these sources are shown in **Figure 16**. Although coal and nuclear power have dominated electricity production, a significant change has occurred leading to reduced use of these fuels for electricity production and greater use of natural gas that is cheaper, cleaner, and more abundant.

3.6 Share of renewable energy

In general, economies that depend on a limited portfolio of non-renewable energy sources are less energy secure than those that are endowed with abundant renewable energy sources. Renewable energy resources are attractive because their supplies are unlimited and inexhaustible so that, unlike non-renewable sources, their consumption today does not reduce the flows available in the future. If adequately developed, they can substitute for non-renewable energy and underpin the transition needed in the energy system to sustainably power economic growth and ameliorate the threat of climate change. Some of the common renewable energy resources that can be harnessed to improve energy security are biomass, hydropower, solar, wind, and geothermal energy. Presently, increasing the share of

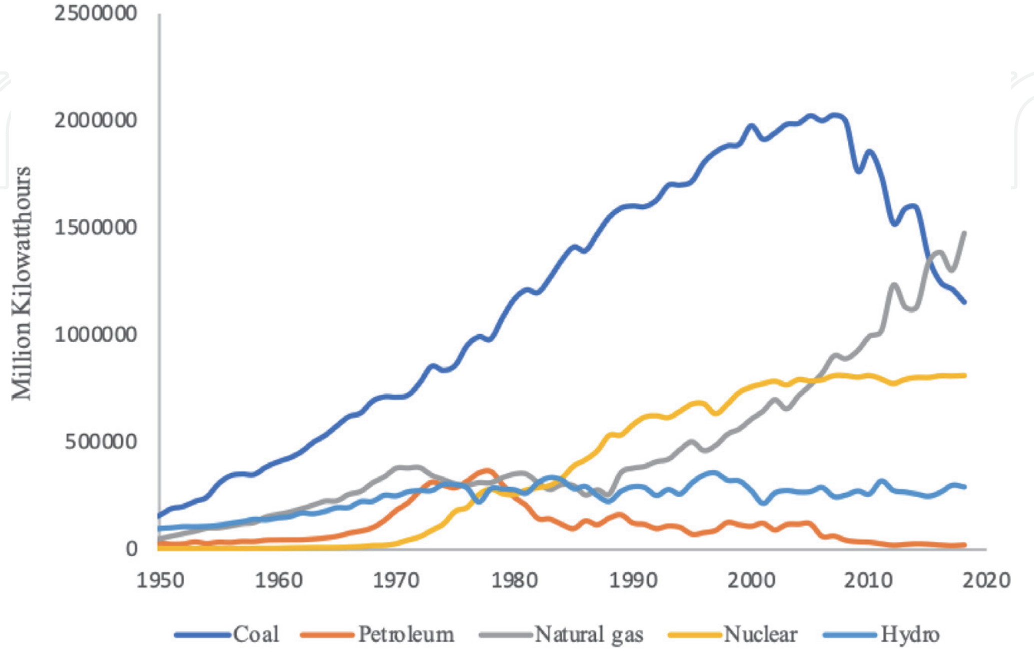

Figure 16.
Electricity generation in US by energy source [30].

renewables in the final energy consumption is a policy priority of many countries as evidenced by the European Union's goal of generating 20% of its electricity from renewables by 2020 [39]. Similarly, the United States has regulations (known as the renewable portfolio standard or renewable electricity standard) obligating electricity supply companies to produce a specific fraction of their electricity from renewable energy sources [40]. In Germany, the Renewable Energy Act mandates that 35% of electricity be produced from renewable sources in 2020 and that this share be increased to 80% by 2050. **Table 7** presents data on the consumption of renewables in the US electric power sector from 1984 to 2018. Over this period, the US electric power sector experienced a significant increase in the use of renewables with wind and solar playing a dominant role. The data in **Table 7**, shows that in 2000, the share of wind and solar in the renewables used to produce electricity was only 2% and that this increased to 49% in 2018. The combined use of wind and solar in electricity production in the US is shown in **Figure 17** and the combined share of wind and solar in the total renewable energy used in the electric power sector is shown in **Figure 18**. The increased use of wind and solar energy has been facilitated by technological innovation and has not only contributed to the diversification of the energy system but also provided several other benefits such improvement in health, savings from reduced fossil use, reduced emissions of greenhouse gases, industrial growth, and the creation of thousands of clean manufacturing jobs.

	Hydro	Geothermal	Solar	Wind	Wood	Waste	Biomass	Total renewable
1984	3352.81	80.81	0.06	0.07	4.82	4.43	9.25	3442.99
1990	3014.01	160.55	3.82	29.01	128.52	187.99	316.51	3523.89
1995	3149.39	137.96	5.12	32.63	125.41	296.25	421.66	3746.77
2000	2767.92	143.76	5.03	57.06	134.32	318.43	452.75	3426.52
2005	2670.13	146.90	5.50	178.09	184.97	220.72	405.70	3406.32
2010	2521.49	148.48	11.76	923.27	195.60	263.78	459.37	4064.37
2015	2307.72	148.34	227.90	1775.71	243.86	281.02	524.88	4984.54
2018	2672.51	153.81	606.97	2530.41	215.11	280.03	495.14	6458.83

Table 7.
Renewable energy use in US electric power sector in trillion of Btu [30].

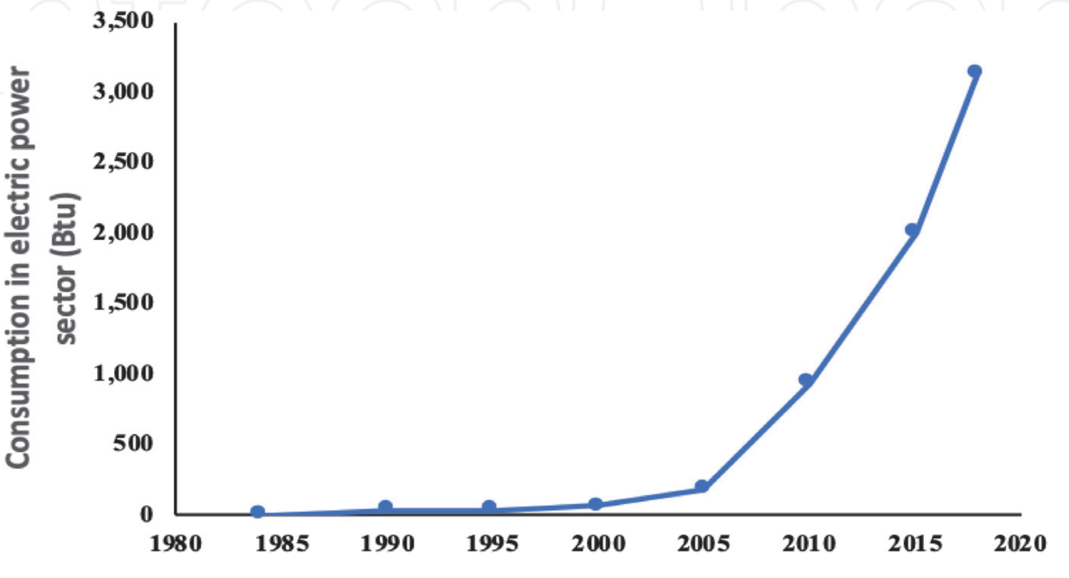

Figure 17.
Combined wind and solar consumption in US electric power sector from 1980 to 2018 (Trillions Btu) [30].

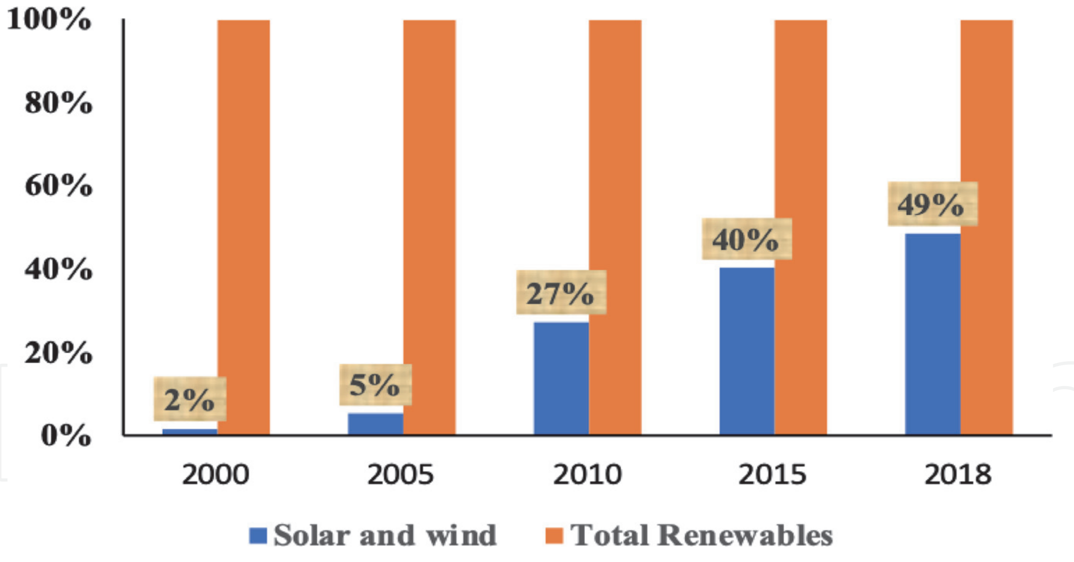

Figure 18.
Share of combined wind and solar in US electric power sector [30].

Further growth in the use of wind and solar power can be expected in the future as the market costs of these technologies continue to fall and as progress is made to overcome the challenges of intermittency.

4. Policy instruments for improving long-term energy security

Energy resources are indispensable to all economies where they are used to power economic growth and to provide households with critical services such as heating, lighting, cooking, and operating equipment and appliances. A secure energy system is vital in averting the economic, social, and political disruptions that can occur if supplies are interrupted [41]. Energy insecurity can precipitate a loss in welfare as a result of the physical unavailability of energy or prices that are volatile and not competitive [41, 42]. Due to the interdependence that characterizes today's energy markets, considerable scope exists for countries to coordinate their energy strategies to reduce their vulnerabilities to energy shocks and improve their overall energy security. Some measures that are currently being used to improve energy security include:

i. *Investments in energy resources and infrastructure*: Countries and/or regions can improve their energy security by undertaking investments that promote exploration, extraction, processing, transportation, and marketing of energy resources. One of the objectives of these initiatives is to upgrade existing energy infrastructure and develop new transmission infrastructure that is crucial to energy security. This is occurring in several regions such as the United States, Africa, and the Caspian Basin. In the United States, for example, previously restrictive regulations have been amended to allow offshore drilling in the Gulf of Mexico, horizontal drilling, hydraulic fracturing, and the drilling for oil and natural gas in the Arctic National Wildlife Refuge in Alaska. These measures have resulted in a substantial increase in oil and natural gas production in the United States and reduced the country's dependence on energy imports. Pipeline projects from the Caspian Basin have also contributed to increasing the supply of oil and natural gas to Europe and Asia. In Africa, the energy infrastructure projects that have recently been commissioned include the Grand Inga Dam in the Democratic Republic of Congo that will produce about 40,000 MW of electricity when completed; the Rusumo Falls Hydroelectric Project in Rwanda that aims to supply about 80 MW of power to Rwanda, Tanzania and Burundi; the Lake Turkana wind power project in Kenya that will provide the country's national grid with about 300 MW of clean power; and, the Jasper Power project in the Northern Cape of South Africa that aims to generate 18 GW of clean energy by 2030. The successful completion of these and similar projects will increase the overall energy supply and enhance energy security.

ii. *Investments in energy efficiency*: Energy efficiency is an important instrument for stemming the growth in energy demand, providing households and firms with cost savings due to reduced energy use, and reducing the emissions of greenhouse gases [43, 44]. According to the International Energy Agency, energy efficiency is the world's most available, secure and affordable energy resource that every government has the power to exploit for widespread benefit [44]. To the extent that energy efficiency actions such as retrofitting homes, adopting more stringent building codes, increasing the fuel economy of vehicles, and adopting more productive technologies in industries reduce energy demand and consumption, they contribute towards the goal of energy security [45]. It is estimated that between 2000 and 2017, improvements in energy efficiency saved an additional 37 exajoules of final energy use in the IEA countries and other major economies and that globally, over this period, efficiency improvements prevented about 12% more energy use [46]. The fact that energy efficiency potential is vast and has not been fully utilized in many countries implies that it is a strategy that can be cost-effectively used to improve energy security. This will entail identifying the barriers to the implementation of energy efficiency programs and addressing these barriers through appropriate policy actions [43].

iii. *Energy diversification*: Countries can enhance their energy security by diversifying the types of energy carriers that their economies depend on and also the sources of their energy supply. Kruyt et al. [17] regard diversification as critical to energy security because the increasing global demand for energy can over time lead to the depletion of currently known energy resources. Yergin [6] notes that energy diversification enhances energy security by allowing societies to absorb shocks in one energy input by increasing the use of other energy inputs. Li [47] asserts that diversifying a country's energy system is vital not only for mitigating the risks that arise from over-reliance on fossil fuels, but also for achieving the goal of sustainable development. Trinidad and Tobago are an example of a country whose primary energy supply is not diverse and consists of 72.3% natural gas and 27.7% crude oil. Canada, in contrast, has a diverse energy mix consisting of natural gas, oil, coal, hydropower, nuclear and others and is therefore much less prone to shortages and price shocks because it is unlikely that these systems would all fail at the same time. Having multiple sources of energy enables countries to continue without disruption if one of the energy sources failed. Over the medium to long-term, Trinidad and Tobago can diversify their energy mix by developing and harnessing their vast potential for wind and solar power.

iv. *Technological innovation*: Technological innovation, like energy efficiency, is a valuable instrument that countries can use to mitigate climate change and enhance their overall energy security. Kim [48] cites Germany and

Japan as examples of countries that are not well endowed with vast oil reserves, but which have invested heavily in alternative energy technologies especially in the transportation sector. These technologies include fuel cells and electric and hybrid vehicles that are increasingly being adopted as a response to the high gasoline prices. Lin and Chen [49] and Lin and Zhu [50] argue that technological innovation is key in developing renewable energy and promoting the transition to a low-carbon economy. Denholm and Hand [51] advance a similar argument and assert that increased grid flexibility and energy storage are critical innovations that are required to achieve high penetration of wind and solar energy. They further claim that in the United States, the limits of wind and solar energy are not resource based; that wind and solar resources are significantly greater than the total electric demand; and, that the primary technical challenge is the resource intermittency that can be addressed through technical innovations that enable energy storage.

The availability of vast supplies of fossil energy resources implies that their increased utilization is a viable strategy that can be used to meet the rising demand for energy and enhance energy security. This option is however not favoured by policy makers who claim that it is likely to increase emissions of carbon dioxide and undermine efforts to mitigate climate change [52]. Carbon capture and storage is a technological innovation that can permit an increase in the use of fossil fuels but curtail the release of stationary carbon dioxide emissions into the atmosphere [53]. According to the IEA [54], more investment needs to be made in carbon capture and storage that has been demonstrated to be a low-cost technological pathway that can help achieve deep decarbonization, promote greater energy security, support diversity of power generation and enhance economic prosperity and employment.

v. *Market and institutional reforms*: Several countries are currently reforming their energy markets to improve security of supply by incentivising investments in secure, low-carbon energy sources; improving efficiency and productivity; supporting cost-effective integration of renewable energy sources; and, improving affordability for consumers [55–57]. Some of the issues that these reforms aim to address are: inadequate electricity generation and distribution infrastructure when electricity demand is growing rapidly [55, 57]; underutilization of cheap resources and overutilization of expensive resources; unnecessary curtailment of renewable energy; existence of barriers to minimizing the cost of power due to inability of energy distribution companies to access all available power generation and the associated marginal costs; lack of flexibility in the energy system; heavy and restrictive regulations that impose costs and hinder innovation; and distortions in energy markets. Examples of reforms that various countries have implemented to address these issues include: liberalization of the downstream gas market in Egypt to end government monopoly, increase competition, and attract foreign direct investment to the energy sector [58]; deregulation of energy prices in China to optimize energy allocation, improve energy efficiency, promote the penetration of renewable energy, and induce energy-saving technologies and innovations [59]; and, expansion of cross-border electricity cooperation and trade through establishment of regional electricity grids in South Asia [60]. Where reforms have been properly designed and implemented, they have increased competition in energy markets, reduced energy prices to

DOI: http://dx.doi.org/10.5772/intechopen.90872

consumers, stimulated technological and structural change, increased the share of renewable energy in the energy mix, increased the reliability of the energy system, reduced power outages, increased investment in the energy sector, and improved energy security [16].

5. Conclusions and implications

Energy resources play a critical role in economic growth and human wellbeing and will continue to be a key concern to policy makers in both developed and developing countries. How energy is produced and used will also continue to be of national and global concern because greenhouse gas emissions from these processes are the primary cause of global warming and climate change. The rapid growth in the demand for energy in recent years due to robust economic expansion, population growth, and new uses of energy is a major challenge that requires policy actions to ensure that energy users have access to reliable, affordable, and secure energy supplies. It is a problematic situation to countries that are not endowed with abundant energy resources and must rely on energy imports. There are however several strategies that countries can implement individually or jointly to improve their energy security. First, agricultural by-products and crop residues such as maize stalks, rice straw, cattle dung, molasses and bagasse can be harnessed and used to produce energy products such as methane which can be used for cooking, heating and lighting [61]. These processes can also be used to produce alcohol which can be used to blend automotive fossil fuels. Energy security can be positively impacted by these measures because they expand the supplies of available energy resources and reduce the demand for conventional energy. Second, countries can increase their energy security by harnessing renewable energy such as wind, solar, and geothermal energy and integrating them into the energy system. This alternative holds considerable promise particularly in regions such as North Africa and the Middle East. Third, through investments in energy efficiency, countries can reduce their demand for energy and enhance their energy security. This can be accomplished through more stringent building codes, market penetration of hybrid and electric cars that have greater fuel economy, and real-time pricing of electricity. Fourth, energy security can be greatly enhanced by improving the performance of energy markets through deep reforms and institutional changes. If properly designed and implemented, the reforms can reduce wastage, incentivise private sector investment in energy generation, increase competition in energy markets reducing the prices to consumers, and improve overall efficiency. Fifth, global energy security can be enhanced through international cooperation on energy issues and the promotion of regional energy trade. Such trade will be a win-win outcome for both exporters and importers of energy.

Author details

Collins Ayoo
Department of Economics, Carleton University, Ottawa, Ontario, Canada

*Address all correspondence to: collins.ayoo@carleton.ca

References

[1] Pode R. Addressing India's energy security and options for decreasing energy dependency. Renewable and Sustainable Energy Reviews. 2010;**14**: 3014-3022

[2] Bompard E, Carpignano A, Erriquez M, Grosso D, Pession M, Profumo F. National energy security assessment in a geopolitical perspective. Energy. 2017;**130**:144-154

[3] Warr BS, Ayre RU. Evidence of causality between the quantity and quality of energy consumption and economic growth. Energy. 2010;**35**(4): 1688-1693

[4] Global Energy Institute (GEI). International index of energy security risk: Assessing risk in a global energy market. 2018. Available at: https://www.globalenergyinstitute.org/energy-security-risk-index

[5] Klare MT. The futile pursuit of "energy security" by military force. The Brown Journal of World Affairs. 2007; **13**(2):139-153

[6] Yergin D. Ensuring energy security. Foreign Affairs. 2006;**85**(2):69-82

[7] Richter PM, Holz F. All quiet on the eastern front? Disruption scenarios of Russian natural gas supply to Europe. Energy Policy. 2015;**80**:177-189

[8] Bohi DR, Toman MA. Energy security: Externalities and policies. Energy Policy. 1993;**21**(11):1093-1109

[9] Bohi DR, Toman MA. The Economics of Energy Security. Deventer: Kluwer Academic Publishers; 1996

[10] Cherp A, Jewell J. The three perspectives on energy security: Intellectual history, disciplinary roots and the potential for integration. Current Opinion in Environmental Sustainability. 2011;**3**(4):202-212

[11] Winzer C. Conceptualizing energy security. Energy Policy. 2012;**46**:36-48

[12] Andrews CJ. Energy security as a rationale for governmental action. IEEE Technology and Society Magazine. 2005;**24**(2):16-25

[13] Jun E, Kim W, Chang H. The analysis of security cost for different energy sources. Applied Energy. 2009; **86**(10):1894-1901

[14] Intharak N, Julay JH, Nakanishi S, Matsumoto T, Sahid EJM, Aquino AGO, et al. A Quest for Energy Security in the 21st Century. Tokyo, Japan: Asia Pacific Energy Research Centre; 2007

[15] World Commission on Environment and Development (WCED). Our Common Future. New York: Oxford University Press; 1987

[16] Grubb M, Butler L, Twomey P. Diversity and security in UK Electricity generation: The influence of low-carbon objectives. Energy Policy. 2006;**34**(18): 4050-4062

[17] Kruyt B, van Vuuren DP, de Vries HJM, Groenenberg H. Indicators for energy security. Energy Policy. 2009;**37**(6):2166-2181

[18] Sovacool BK. Reassessing energy security and the trans-ASEAN natural gas pipeline network in Southeast Asia. Pacific Affairs. 2009;**82**:467-486

[19] Sovacool BK. The Routledge Handbook of Energy Security. London: Routledge; 2010

[20] Sovacool BK. Evaluating energy security in the Asia Pacific: Towards a more comprehensive approach. Energy Policy. 2011;**39**(11):7472-7479

[21] Sovacool BK. An international assessment of energy security performance. Ecological Economics. 2013;**88**:148-158

[22] Sovacool BK, Brown MA. Competing dimensions of energy security: An international review. Annual Review of Environment and Resources. 2010;**35**:77-108

[23] Sovacool BK, Mukherjee I. Conceptualizing and measuring energy security: A synthesized approach. Energy. 2011;**36**(8):5343-5355

[24] Sovacool BK, Mukherjee I, Drupady IM, D'Agostino AL. Evaluating energy security performance from 1990 to 2010 for eighteen countries. Energy. 2011;**36**(10):5846-5853

[25] Brown MA, Sovacool BK. Climate Change and Global Energy Security: Technology and Policy Options. Cambridge, MA: MIT Press; 2011

[26] Badea AC, Rocco SCM, Tarantola S, Bolado R. Composite indicators for security of energy supply using ordered weighted averaging. Reliability Engineering and System Safety. 2011; **96**(6):651-662

[27] Brown MA, Wang Y, Sovacool BK, D'Agostino AL. Forty years of energy security trends: A comparative assessment of 22 industrialized countries. Energy Research & Social Science. 2014;**4**:64-77

[28] Asia Pacific Energy Research Centre (APERC). A Quest for Energy Security in the 21st Century: Resources and Constraints. Japan: Tokyo; 2007

[29] van den Bremer TS, van der Ploeg F. Managing and harnessing volatile oil windfalls. IMF Economic Review. 2013; **61**(1):130-167

[30] BP Statistical Review of World Energy. 2018

[31] International Energy Agency (IEA). Global Gas Security Review 2018: Meeting Challenges in a Fast Changing Market. Paris: OECD/IEA; 2018. Available from: https://webstore.iea.org/global-gas-security-review-2018

[32] International Energy Agency (IEA). World Energy Outlook. Paris: OECD/IEA; 2018

[33] Neelawela UD, Selvanathan EA, Wagner LD. Global measure of electricity security: A composite index approach. Energy Economics. 2019;**81**: 433-453

[34] Lesbirel S. Diversification and energy security risks: The Japanese case. Japanese Journal of Political Science. 2004;**5**(1):1-22

[35] Hasanov M. An analysis of economic benefits of the Southern Gas Corridor. Energy Sources, Part B: Economics, Planning, and Policy. 2016;**11**(11): 999-1005

[36] Morningstar R. The legacy of the Southern Gas Corridor. Turkish Policy Quarterly. 2018;**17**(3):39-44

[37] Chen X, Huang H, Khanna M, Önal H. Alternative transportation fuel standards: Welfare effects and climate benefits. Journal of Environmental Economics and Management. 2014; **67**(3):241-257

[38] Flynn PC. Commercializing an alternate vehicle fuel: Lessons learned from natural gas for vehicles. Energy Policy. 2002;**30**(7):613-619

[39] Jansen J, van der Welle A. The role of regulation in integrating renewable energy: The EU electricity sector. In: Goldthau A, editor. The Handbook of Global Energy Policy. Wiley-Blackwell; 2013. pp. 322-339

[40] Barbose G, Wiser R, Heeter J, Mai T, Bird L, Bolingera M, et al.

A retrospective analysis of benefits and impacts of U.S. renewable portfolio standards. Energy Policy. 2016;**96**: 645-660

[41] Barton B, Redgwell C, Rønne A, Zillman DN. Energy Security: Managing Risk in a Dynamic Legal and Regulatory Environment. Oxford, UK: Oxford University Press; 2004

[42] Höök M, Tang X. Depletion of fossil fuels and anthropogenic climate change—A review. Energy Policy. 2013;**52**: 797-809

[43] Ayoo C. The role of efficiency in energy policy. International Journal of Environment and Sustainable Development. 2016;**15**(4):423-449

[44] International Energy Agency (IEA). Energy Efficiency 2017. Paris: OECD/IEA; 2017

[45] Nepal R, Jamasb T, Tisdell CA. Market-related reforms and increased energy efficiency in transition countries: Empirical evidence. Applied Economics. 2014;**46**(33):4125-4136

[46] International Energy Agency (IEA). Energy Efficiency 2018. Paris: OECD/IEA; 2018

[47] Li X. Diversification and localization of energy systems for sustainable development and energy security. Energy Policy. 2005;**33**(17):2237-2243

[48] Kim JE. Energy security and climate change: How oil endowment influences alternative vehicle innovation. Energy Policy. 2014;**66**: 400-410

[49] Lin B, Chen Y. Does electricity price matter for innovation in renewable energy technologies in China? Energy Economics. 2019;**78**:259-266

[50] Lin B, Zhu J. The role of renewable energy technological innovation on climate change: Empirical evidence from China. Science of the Total Environment. 2019;**659**:1505-1512

[51] Denholm P, Hand M. Grid flexibility and storage required to achieve very high penetration of variable renewable electricity. Energy Policy. 2011;**39**(3): 1817-1830

[52] Hoffert MI. Farewell to fossil fuels? Science. 2010;**329**(5997):1292-1294

[53] Mikunda T, Kober T, de Coninck H, Bazilian M, Rösler H, van der Zwaan B. Designing policy for deployment of CCS in industry. Climate Policy. 2014;**14**(5): 665-676

[54] International Energy Agency (IEA). Five Keys to Unlock CCS Investment. Paris: OECD/IEA; 2017

[55] Department of Energy and Climate Change (DECC). Electricity Market Reform: Policy Overview. 2012. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/65634/7090-electricity-market-reform-policy-overview-.pdf

[56] International Energy Agency (IEA). Electricity Market Reform: An IEA Handbook, Energy Market Reform. Paris: OECD/IEA; 2000

[57] Patel D. India kick-starts wholesale electricity market reforms. 2019. Available at: https://energypost.eu/india-kick-starts-wholesale-energy-market-reforms/

[58] Elshazly M, Khodeir S. Legislative reforms in the Egyptian energy sector to liberalize the natural gas market. Journal of World Energy Law and Business. 2018;**11**:354-359

[59] Fan Y, Liao H, Wei Y. Can market oriented economic reforms contribute to energy efficiency improvement?

Evidence from China. Energy Policy. 2007;**35**(4):2287-2295

[60] Timilsina GR, Toman M. Potential gains from expanding regional electricity trade in South Asia. Energy Economics. 2016;**60**:6-14

[61] Ayoo C, Bonti-Ankomah S. Economic impacts of value addition to agricultural byproducts. In: Simpson BK, Aryee ANA, Toldra F, editors. Byproducts from Agriculture and Fisheries: Adding Value for Food, Feed, Pharma, and Fuels. Hoboken, NJ: Wiley; 2020. pp. 685-698