1

Introduction

For centuries energy has played a major role in the evolution of human civilizations. In the last two centuries fossil fuels (coal, oil, and natural gas) were crucial for the birth and development of the Industrial Revolution and global economic prosperity. Energy products are certain to maintain their character as the "engine" for maintaining and improving our way of life.

A major characteristic of energy is the mismatch between resources and demand. Generally speaking, major consuming regions and nations (the United States, Europe, Japan, China, and India) do not hold adequate indigenous energy resources to meet their large and growing consumption. On the other hand, major producers (i.e., the Middle East, Russia, the Caspian Sea, and Africa) consume a small (albeit growing) proportion of their energy resources. This broad global mismatch between consumption and production has made energy products the world's largest traded commodities. Almost every country in the world imports or exports a significant volume of energy products. This means the wide fluctuation of energy prices plays a key role in the balance of payments almost everywhere.

The heavy reliance on energy in conjunction with the asymmetric global distribution of energy deposits have underscored the importance of energy security. This sense of vulnerability is not new. Despite the abundance of energy resources and a favorable political and economic environment, industrialized countries started expressing their concerns over energy security as early as the first part of the twentieth century. First Lord of the Admiralty Winston Churchill's decision that the Royal Navy needed to convert from coal to oil in order to retain its dominance signaled a growing intensity of global competition over energy resources (mainly oil). This rivalry between global powers was played out in World War II when the Allies enjoyed access to significant oil deposits while Germany's and Japan's strategies to gain access to oil resources failed and led, among other developments, to their eventual defeat.

The availability of cheap energy resources played a major role in the reconstruction and development of Europe and Japan in the aftermath of World War II. This prolonged era of relative confidence in the availability of abundant and secure energy resources came to an abrupt end following the outbreak of the 1973 Arab–Israeli War. Arab oil producing countries cut their production and imposed oil embargos on the United States and a few other countries to force a change in their political support for Israel. This use of oil by major producers to gain political leverage has shattered consumers' sense of energy security. Since then, the fluctuation

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of energy prices (partly due to geopolitical developments and partly in response to supply and demand changes) has reinforced this sense of vulnerability.

In the last few decades there has been a growing understanding of the challenges that climate change poses to life on earth. More people have come to realize that our way of life (i.e., human activities) contributes and accelerates global warming and that something needs to be done to restrain this human-made environmental deterioration. This slowly growing consensus has added a new dimension to energy security. The concept is no longer limited to the availability of energy resources at affordable prices. Environmental considerations restrain the exploration and development of these resources and urge consideration of less polluting alternative sources of energy.

This brief overview of energy history suggests that there is a wide variety of threats to energy security. These include geological, geopolitical, economic, and environmental threats. In the following chapters I thoroughly examine these challenges on both the consumer and producer sides. In the remainder of this chapter I provide a detailed discussion of the concept of energy security followed by an analysis of the different forms of energy (i.e., oil, natural gas, coal, nuclear power, and renewable sources). The discussion highlights the main themes that characterize the global energy markets.

1.1 Energy Security

The 1973–1974 oil embargo served as a turning point in global and domestic energy markets. The availability of energy supplies at affordable prices was no longer taken for granted. The turmoil in the world economy focused on the disruption of supplies to consuming countries. These oil consumers have implemented several measures (individually and collectively) to mitigate the impact of such disruptions and to reduce their energy vulnerability. The measures include the creation of the International Energy Agency (IEA), the storage of oil supplies in strategic petroleum reserves, and encouraging energy conservation, among others.

Not enough attention was given to the other side of the energy equation – producing nations. The concept of "energy security" is not static. Since the mid-1970s a broader definition has emerged that addresses all the energy players' concerns. In the past few decades, while the industrialized countries have successfully diversified their sources of crude oil imports and greatly reduced their relative dependence on energy (albeit at different degrees), the major oil exporters remained dependent on oil revenues. Petroleum revenues have continued to be the principal source of income for almost all major oil exporting countries. As a result, oil exporters have as many reasons to worry about the security of their markets as importers have to worry about the security of supplies [1]. In short, the security of demand is considered as important as the security of supply. Abdullah Salem El-Badri, Secretary General of the Organization of Petroleum Exporting Countries (OPEC), summed up the argument: "Energy security should be reciprocal. It is a two-way street" [2].

Within this context energy analysts have provided different definitions of energy security highlighting different aspects of the concept. Barry Barton, Catherine Redgwell, Anita Ronne, and Donald Zillman define it as a condition in which "a nation and all, or most of its citizens and businesses have access to sufficient energy resources at reasonable prices for the foreseeable future free from serious risk or major disruption of service" [3]. Daniel Yergin underscores a number of "fundamentals of energy security." The list includes diversification; high-quality and timely information; collaboration among consumers and between consumers and producers; investment flows; and research and development technological advance [4]. Yergin argues that the experience since the early 2000s has highlighted the need to expand the concept of energy security in two critical dimensions: globalization of the energy markets and the need to protect the entire energy supply chain and infrastructure [5].

Christian Egenhofer, Kyriakos Gialoglou, and Giacomo Luciani distinguish between short-term and long-term risks. The former are generally associated with supply shortages due to accidents, terrorist attacks, extreme weather conditions or technical failure of the grid. The latter are associated with the long-term adequacy of supply, the infrastructure for delivering this supply to markets, and a framework for creating strategic security against major risks (such as non-delivery for political, economic, force majeure or other reasons) [6].

Finally, a report by the IEA argues that energy insecurity stems from the welfare impact of either the physical unavailability of energy, or prices that are not competitive or overly volatile. Analysts at the Paris-based organization add that the more a country is exposed to high-concentration markets, the lower is its energy security [7].

All these definitions underscore the fact that energy security is a multi-dimensional concept that incorporates cooperation between producers, consumers, and national and international companies. The experience of the last few decades indicates that the availability of clean energy resources at affordable prices cannot be addressed only at a national level. Rather, international cooperation is a necessity. Thus, energy is part of broader international relations between states. A major theme of today's energy markets is interdependence between consumers and producers. Calls for self-sufficiency or energy independence are more for domestic constituencies. Indeed, energy interdependence fosters cooperation between countries in other areas such as economic development and world peace.

Another major theme of the energy security literature is the importance of diversification of energy mix and energy sources. The less dependent a country is on one form of energy (i.e., oil, natural gas, coal, nuclear power, and renewable sources), the more secure it is. Similarly, the more producing regions there are around the world, the better.

1.2 Diversification of Energy Mix

To a great extent coal was the dominant fuel for most of the nineteenth century and was overtaken by oil in the twentieth century. The transition from coal to oil was due to the general superiority of oil. It has a higher energy density (about 1.5 times higher than the best bituminous coals, commonly twice as high as ordinary steam coals), it is a cleaner as well as a more flexible fuel, and it is easier both to store and to transport [8]. In the early years of the twenty-first century many countries took steps to utilize the world's endowment of natural gas, renewable sources, and nuclear power. The IEA projects that fossil fuels will account for 80% of the world's primary energy mix in 2030 [9]. This means that, despite the renaissance in nuclear power and the growing interest in other alternative fuels, oil, natural gas, and coal will continue to dominate the global energy mix. This projection suggests that countries from all over the world should keep investing and developing these alternative sources of energy while pursuing strategies to produce and deliver fossil fuels to end-users in an efficient, timely, sustainable, economic, reliable, and environmentally sound manner.

1.2.1 Oil

Oil is the world's most vital source of energy and is projected to remain so for many years to come, even under the most optimistic assumptions about the pace of development and deployment of alternative fuels.

Crude oil is classified by density and sulfur content. Crude oil with a lower density (referred to as light crude) usually yields a higher proportion of the more valuable final petroleum products, such as gasoline and other light petroleum products, by a simple refining process known as distillation. Light crude oil is contrasted with heavy crude oil, which has a low share of light hydrocarbons and requires much more severe refining processes than distillation, such as coking and cracking, to produce similar proportions of the more valuable petroleum products.

Sulfur, a naturally occurring element in crude oil, is an undesirable property and refiners have to make heavy investments in order to remove it from crude oil. Crude oil with a high sulfur content is referred to as sour crude, while that with a low content of sulfur is referred to as sweet crude. Crude oil that yields a higher proportion of the more valuable final petroleum products and requires a simple refining process (the light/sweet crude variety) is more desirable and considered superior to the one that yields a lower fraction of the more valuable petroleum products and requires a more severe refining process (the heavy/sour crude variety) [10].

The birth of the oil industry is generally attributed to the famous well drilled for oil in 1859 by Colonel Edwin L. Drake at Titusville, Pennsylvania [11]. Also, it is claimed that F.N. Semyenov was the first to drill a well on the Apsheron Peninsula, near Baku in Azerbaijan, in 1848 [12]. In the succeeding years the oil industry grew rapidly in both the United States and on the shores of the Caspian Sea. For most of the following century the United States and its oil companies dominated the industry. This US domination was seriously challenged in the 1960s and 1970s due to at least two significant developments. First, US oil production peaked and the nation ceased to be self-sufficient and started a steady and growing dependence on foreign supplies. Second, major oil producing nations founded OPEC to defend their interests and the opportunity came in the aftermath of the 1973 Arab–Israeli War. In the twenty-first century, the oil industry is no longer dominated by one player or a small number of international oil companies. Rather, multiple producers, consumers, national and international companies compete with one another and also work together to explore, develop, and deliver approximately 85 million barrels of oil a day.

The IEA projects that oil will continue to dominate the global energy mix, so its share will slightly decline from 34% in 2007 to 30% by 2030 [13]. This persistent domination raises a key question – does the world hold enough oil to meet the growing demand? Furthermore, sustainable supplies require adequate investment. The flow of investments needs a supportive geopolitical environment. The following sections address these issues.

Unlike solar, wind, and other renewable energy forms, oil (and other fossil fuels) is a finite resource. This fact suggests that global production will peak one day and eventually the world will run out of oil. This is known in the oil literature as peak oil theory. Its roots go back to Marion King Hubbert, a Shell geologist, who in 1956 correctly predicted that US production would peak between 1965 and 1970 [14]. His model maintains that the production rate of a finite resource follows a largely symmetrical bell-shaped curve. This theory has since ignited an intense debate regarding the availability of enough supplies to meet global demand and the future of oil in general. Peter Odell agrees that production does indeed go up, and then down, and that the downside usually falls off gradually, "following a depletion pattern modeled fairly accurately by production that is a fixed percentage of what remain (i.e., exponential decline)" [15].

Most of the world's oil executives, government ministers, analysts and consultants reject the peak oil theory on both technological and economic grounds. They argue that technological advances and market laws have always expanded the lifespan of the world's endowment of proven oil reserves.

In the oil industry a distinction is made between proven, probable and possible reserves. Proven reserves are those quantities of petroleum which geological and engineering data indicate with reasonable certainty (90% probability that the actual quantities recovered will exceed the estimate) can be recovered in the future from known reservoirs, under existing economic and operating conditions [16]. Probable reserves are those unproven reserves which analysis of geological and engineering data suggests are more likely than not (50% probability) to be commercially recoverable. Possible reserves are those unproven reserves which analysis of geological and engineering data suggests are less likely than probable reserves to be commercially recoverable (10% probability) [17]. It is important to point out that in most oil producing countries data on reserves are considered state secrets and foreign observers are not allowed to verify the accuracy of official figures [18].

Another distinction is made between conventional and non-conventional oil. The former flows at high rates and with a good quality. Much of conventional oil comes from giant fields discovered a long time ago. Most of the oil that the world currently consumes is considered conventional oil. On the other hand, non-conventional oil comes from enhanced recovery achieved by changing the characteristics of the oil in the reservoir through steam injection and other methods. Non-conventional oil exists in hostile environments, usually in small accumulations and with a poor quality. It is difficult and expensive to produce and is environmentally challenging. Examples include heavy oil and tar-sand deposits in western Canada, Venezuela, and Siberia [19].

Oil extraction techniques are advancing all the time. Technological advances have enabled oil companies to extract more oil from existing fields and avoid unsuccessful drilling. The clear successes of the late 1950s, 1960s, and 1970s in finding oil were largely due to the expanding use of seismic surveys, with digital seismic surveys, in particular, being introduced from the mid-1960s. Furthermore, a substantial increase in world oil production in the last few decades has come from offshore fields. Modern technology has enabled oil companies to find and develop oil deep at the bottom of the oceans. Offshore oil production started in the early 1940s and has grown from a modest 1 million barrels per day (b/d) in the 1960s to nearly 25 million b/d in 2005 to represent one-third of world crude oil production [20]. In short, what was considered non-conventional is increasingly regarded as conventional.

Technology is also reducing the cost of exploration and development. When the world comes close to exhausting oil deposits, prices will gradually move higher as the costs of alternative energy decline. In short, it can be argued that the world is running out of easy and cheap oil, but there is still plenty to explore and develop. The IEA projects that the world's total endowment of oil is large enough to support the anticipated rise in consumption in the foreseeable future [21].

1.2.2 Natural Gas

Natural gas is a fossil fuel that contains a mix of hydrocarbon gases, mainly methane, along with varying amounts of ethane, propane, and butane. Carbon dioxide, oxygen, nitrogen, and hydrogen sulfide are also often present. Natural gas is "dry" when it is almost pure methane, absent the longer-chain hydrocarbons. It is considered "wet" when it contains other hydrocarbons in abundance. "Sweet" gas possesses low levels of hydrogen sulfide compared to "sour" gas [22]. Natural gas found in oil reservoirs is called "associated gas." When it occurs alone it is called "non-associated gas."

Natural gas is rapidly gaining importance in global energy markets. Prized for its relatively clean and efficient combustion, gas is becoming the fuel of choice for a wide array of uses, notably the generation of electric power. World natural gas reserves are abundant, estimated at about 185.02 trillion cubic meters (6534.0 trillion cubic feet), or 60.4 times the volume of natural gas used in 2008 [23].

Ancient civilizations used gas on a small scale but it has been used extensively as a fuel source since the nineteenth century. With the discovery of oil in Pennsylvania, associated gas was used for both industrial and domestic purposes. The growing need for energy during and in the aftermath of World War II gave momentum to gas exploration and development. An extensive pipeline network was built in parallel with the expansion of gas production. Thus, by the middle of the twentieth century, natural gas provided about a third of total primary energy in the United States and the nation was by far the main natural gas producer and consumer in the world [24].

In the 1950s and 1960s several natural gas discoveries were made in Europe, particularly in and around the North Sea. The turmoil in oil markets, caused by the 1973–1974 Arab embargo, gave more incentives to consuming countries to diversify their energy mix. Since then natural gas has become an important source of energy worldwide. Still, the problem of transporting natural gas slowed down the full utilization of global deposits. Pipelines, the main method of transporting natural gas, imposed severe limitations on trade in the fuel. By nature, pipelines are economical for trade over relatively small (though growing) distances, and thus markets made through pipes were regional in nature.

The introduction of liquefied natural gas (LNG) in the early 1960s changed the dynamics of the gas industry and trade. LNG is natural gas that is stored and transported in liquid form under atmospheric pressure at a temperature of −260 °F (−160 °C). Like the natural gas that is delivered by pipeline into homes and businesses, it mainly consists of methane. Liquefying natural gas provides a means of moving it long distances when pipeline transport is not feasible. Natural gas is turned into a liquid using a refrigeration process in a liquefaction plant. The unit where LNG is produced is called a train. Liquefying natural gas reduces its volume by a factor of 610. The reduction in volume makes the gas practical to transport and store. In international trade, LNG is transported in specially built tanks in double-hulled ships to a receiving terminal where it is stored in heavily insulated tanks. The LNG is then sent to regasifiers which turn the liquid back into a gas that enters the pipeline system for distribution to customers as part of their natural gas supply [25].

The development of LNG was slow due to the costly technologies associated with producing, storing, and shipping it. In the late 1950s and early 1960s the technology for shipping LNG was developed and the world's first major LNG export plant opened in Arzew, Algeria, in 1964, exporting gas to buyers in France and the United Kingdom. By 1972, LNG plants were up and running in the United States (Alaska), Brunei, and Libya, with a second plant added in Algeria at Skikda. In the ensuing decades Algeria, Indonesia, Malaysia, Australia, Qatar, Nigeria, Trinidad and Tobago, Oman, and Egypt have emerged as major LNG exporters [26]. The expansion in LNG trade is due mainly to technological advances which substantially reduced the costs. Furthermore, the speedy rise of LNG has the potential to transform the natural gas market from a regional to an international one. In other words, high costs made it more convenient to transport natural gas short distances. Declining costs are making it easier to ship LNG almost anywhere in the world.

Still, compared to oil, gas is more capital intensive; project time horizons are longer, and wariness about uncertain political environments appears to be greater. In addition, natural gas is used mainly in electric power generation, where it has to compete with coal, nuclear power, and hydroelectricity. Oil, by contrast, is still the unrivaled king of energy sources for mobility.

1.2.3 Coal

Coal is a readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50% by weight and more than 70% by volume of carbonaceous material. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geological time [27].

Compared to other fuels, coal enjoys several advantages. It is abundant and more evenly distributed around the world than oil or natural gas. It is cheap and costs are continuously being reduced by competition [28]. The many suppliers and the possibility of switching from one to another means security of supply. The global ratio of coal reserves to production is 120 years [29]. Coal is widely used in electricity generation (about 40% of the world's electricity) [30]. On the other hand, coal faces significant environmental challenges in mining, air pollution and emission of carbon dioxide (CO_2). Indeed, coal is the largest contributor to global CO_2 emissions from energy use and its share is projected to increase [31].

CO_2 is a colorless, odorless, non-poisonous gas that is a normal part of the earth's atmosphere. It is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it taps heat (infrared energy) radiated by the earth into the atmosphere and thereby contributes to the potential for global warming. The challenge for governments and industry is to find a path that mitigates carbon emissions yet continues to utilize coal to meet urgent energy needs. This will require not only clean coal technologies for new plants, but also rehabilitation and refurbishment of existing inefficient plants. And this must happen not only in industrialized countries, but also in developing countries, which are expected to account for most coal consumption in the foreseeable future.

Faced with the reality that coal will be a major source of energy for a long time, it becomes clear that cleaner, lower-carbon, coal-based energy technologies will play a central role in solving the global climate challenge. Those technologies include coal gasification, which makes clean gas from coal and strips out the CO_2 before burning the gas, and post-combustion capture, which strips CO_2 out of the exhaust gas left after coal is burned. Another rapidly developing method is carbon capture and storage (CCS), a technique that has been around for decades. This approach is designed to mitigate the contribution of fossil-fuel emissions to global warming, based on capturing CO_2 from large point sources such as fossil-fuel power plants. It can also be used to describe the scrubbing of CO_2 from ambient air as a geo-engineering technique. The CO_2 might then be permanently stored away from the atmosphere [32].

The intense fluctuation in oil and natural gas prices has revived interest in the use of Fischer–Tropsch (F–T) technology to produce transportation fuels from coal. The F–T process is a catalyzed chemical reaction in which carbon monoxide and hydrogen are converted into liquid hydrocarbons of various forms. The principal purpose of this process is to produce a synthetic petroleum substitute for use as synthetic lubrication oil or as synthetic fuel [33]. The process was invented in petroleum-poor but coal-rich Germany in the 1920s to produce liquid fuels. It was used by Germany and Japan during World War II to produce ersatz fuels. Later, the process was used in South Africa to meet its energy needs during its isolation under the apartheid regime. This process has received renewed attention in the quest to produce low-sulfur diesel fuel in order to minimize the environmental impact from the use of diesel engines. The F–T process is an established technology and already applied on a large scale, although its popularity is hampered by high capital costs, high operation and maintenance costs, and the uncertain and volatile price of crude oil.

These decades-long efforts to mitigate emissions suggest that coal will continue to be used to meet the world's energy needs in significant quantities. Indeed, the IEA projects that coal's share of global energy demand will climb from 26% in 2006 to 29% in 2030 [34].

1.2.4 Nuclear Power

The fact that nuclear power releases virtually no environmentally damaging emissions of carbon dioxide, sulfur dioxide, and nitrogen oxide could make it an attractive option for many countries seeking technologies leading to reduced greenhouse gas emissions or abatement of local and regional pollution. In the 1960s and 1970s, particularly after the Arab oil embargo, nuclear power promised to be a viable solution for industrialized countries looking for energy security and cheap power. However, most of the promise of nuclear energy has evaporated as a result of loss of investor and public confidence in the technology.

At the beginning of the twenty-first century there were approximately 440 nuclear reactors in use around the world and about 26 under construction. Most of these reactors are concentrated in 31 countries. Just six countries – the United States, France, Japan, Germany, Russia, and South Korea – produce almost three-quarters of the nuclear electricity in the world [35]. Nuclear power is almost exclusively used for electricity generation and globally it produces about 16% of electricity.

Since the early 2000s there has been a global revival of interest in nuclear power. Almost all over the world, governments are taking a second look at nuclear power, particularly in Europe, North America, Asia, and most recently in the Middle East. As a result, several reactors are being built or under consideration. Several developments have contributed to this "nuclear renaissance." First, the surge in oil and natural gas prices in the early 2000s and the great uncertainty surrounding the future of these two fuels have prompted many governments to diversify their energy mix and reduce their over-dependence on hydrocarbon fuels. Second, Russia's politically motivated, frequent use of its oil and gas deposits to punish and/or reward clients has deepened Europe's sense of vulnerability and put more pressure on European leaders to reduce their dependence on Moscow. Third, the emerging and growing consensus on climate change has made many countries more determined to contain pollution and honor their commitments on climate change international agreements, particularly the Kyoto Protocol. However, many world leaders have come to realize that they cannot maintain their non-nuclear energy policy and simultaneously fulfill their commitments to reduce CO_2 emissions. Finally, since the Chernobyl disaster in 1986 there has not been a major nuclear accident. Indeed, the industry safety record has made substantial improvements. Furthermore, several countries have figured out ways to deal with nuclear waste without endangering the health of their populations [36]. These developments have made nuclear power more attractive and contributed to the wave of new construction of nuclear plants.

Despite this renewed global interest in nuclear power, several issues need to be addressed before it reaches its full potential. These include costs, safety, radioactive waste disposal, and proliferation of nuclear weapons.

Cost: Like the other sources of energy, nuclear power will succeed in the long run only if it has a lower cost than competing fuels. Nuclear power plants have relatively high capital costs and very low marginal operating costs. Construction costs reflect a combination of regulatory delays, redesign requirements, and construction management and quality control problems. The specter of high construction costs has been a major factor leading to little credible commercial interest in investments in new nuclear plants. However, a closer look suggests that nuclear power costs might not be very high if the costs of CO_2, produced by fossil fuels, are taken into consideration. Furthermore, as engineering companies acquire more expertise, there will be substantial reductions in construction costs.

Safety: After the 1979 accident at Three Mile Island, Pennsylvania, in the United States and the 1986 disaster at Chernobyl in the Soviet Union, public concern about reactor safety increased substantially. There is also concern about the transportation of nuclear materials and waste management. The September 11, 2001 terrorist attacks on the World Trade Center and the Pentagon have heightened concerns about the vulnerability of nuclear power stations and other facilities, especially spent-fuel storage pools, to terrorist attack. There is concern about the exposure of citizens and workers to radiation from the activities of the industry despite good regulations. There are also significant environmental impacts, ranging from long-term waste disposal to the handling and disposal of toxic chemical wastes associated with the nuclear fuel cycle.

Radioactive waste disposal: Spent nuclear fuel discharged from nuclear reactors will remain highly radioactive for many thousands of years. The management and disposal of this radioactive waste from the nuclear fuel cycle is one of the most difficult problems facing the nuclear power industry. The primary goal of nuclear waste management is to ensure that the health risks of exposure to radiation from this material are reduced to an acceptably low level for as long as it poses a significant hazard. One strategy involves the separation of individual radionuclides from the spent fuel. Another strategy is to dispose of the waste in repositories constructed in rock formations hundreds of meters below the earth's surface. Each strategy has its own advantages and disadvantages. The lack of consensus on the most appropriate way to deal with radioactive waste stands as one of the primary obstacles to the expansion of nuclear power around the world.

Proliferation of nuclear weapons: A major challenge facing nuclear power is the so-called "dual use" of nuclear material and know-how. In other words, the same material (enriched uranium and plutonium) and applied technology that are used to make peaceful nuclear power can be used to make nuclear weapons. This means that nations wishing to acquire or enhance a nuclear weapons capability can use commercial nuclear power as a source of technological know-how or usable material for nuclear weapons. The possession of a complete nuclear fuel cycle, including enrichment, fuel fabrication, reactor operation, and reprocessing, moves any nation closer to obtaining a nuclear weapons capability [37]. The crisis with North Korea and the international concern over Iran's nuclear program illustrate this dilemma.

Since the dawn of the nuclear age, proliferation concerns have led to an elaborate set of international institutions and agreements, none of which have proven entirely satisfactory. The nuclear Non-proliferation Treaty (NPT) is the major international mechanism to prevent nations from acquiring nuclear weapons capability. The International Atomic Energy Agency (IAEA) is responsible for verifying NPT compliance with respect to fuel cycle facilities through its negotiated safeguards agreements with NPT signatories. In addition, many policy-makers and proliferation experts have proposed the creation of an international fuel bank, under IAEA supervision, that would assure nations' supply of nuclear fuel as long as they observe the NPT's provisions [38].

To sum up, unless these issues (costs, safety, radioactive waste disposal, and proliferation of nuclear weapons) are satisfactorily addressed, nuclear power is unlikely to realize its potential. Indeed, nuclear power's share of the global energy mix is projected to decline slightly from 6% in 2008 to 5% by 2030 and its share of electricity output to drop from 16% to 10% during the same time span [39].

1.2.5 Biofuels

In recent years, biofuels have attracted increasing attention. Their main attraction is that they are made from renewable feedstocks that can be grown by farmers, and substituting them for petroleum products reduces greenhouse gases and dependence on foreign oil. In short, biofuels have been promoted as serious solutions to the twin challenges of climate change and energy security. It is no surprise, then, that global interest in bio-energy has grown rapidly in recent years. In the early 2000s, bio-energy became a multi-billion-dollar business. The United States and Brazil dominate the current liquid biofuels industry, but many other governments, particularly Australia, Canada, and Europe, are now actively considering the appropriate role for biofuels in their future energy portfolios.

Bio-energy is defined as energy produced from organic matter or biomass [40]. A wide range of biologically derived feedstocks can be transformed into liquid fuels. The technologies used to make that transformation are also numerous. At present, the predominant liquid biofuels in use are ethanol and biodiesel. Ethyl alcohol, or ethanol, can be produced from any feedstock that contains relatively dense quantities of sugar or starchy crops. The most common feedstocks are sugar cane, sugar beet, maize (corn), wheat, and other starchy cereals such as barley, sorghum, and rye. Biodiesel is based on vegetable oils such as those obtained from oil palm, rapeseed, sunflower seed, and soybean; some is made from tallow, used cooking oil, and even fish oil [41].

The global interest and impressive development of the biofuel industry have raised serious concerns about its impact on food prices, climate change, and energy security.

Food prices: To the extent that increased demand for biofuel feedstock diverts supplies of food crops (e.g., maize) and diverts land from food crop production, global food prices will increase. The competition over land and water has heightened the so-called "food-versus-fuel debate." This competition favors large producers, as illustrated by the prevailing trend toward concentration of ethanol ownership in Brazil and the United States. The transition to liquid biofuels can be especially harmful to farmers who do not own their own land, and to the rural and urban poor who are net buyers of food, as they could suffer from even greater pressure on already limited financial resources. Though it is true that increased use of biofuels has contributed to a surge in grain and vegetable oil prices, other factors such as droughts and the rise in demand for meat and milk products have probably played a role in the overall high food prices [42].

Climate change: The potential impact of biofuels on the environment is uncertain and needs to be closely scrutinized. Several elements need to be taken into account. These include the type of crop, the amount and type of energy embedded in the fertilizer used to grow the crop, emissions from fertilizer production, the energy used in gathering and transporting the feedstock to the bio-refinery, alternative land uses, and the energy intensity and fuel types used in the conversion process. In addition, water availability will influence feedstock choice and the location of conversion facilities. Finally, it is important to point out that the ability of various bio-energy types to reduce greenhouse gas emissions varies widely.

Energy security: Reducing dependence on fossil fuels has been a major reason for investing in bio-energy. The idea of producing energy at home and becoming self-sufficient instead of being vulnerable to interruption of foreign supplies appeals to many policy-makers. Again, this strategy needs to be scrutinized. At least two dynamics should be taken into consideration. First, fossil fuels are used in the production and transportation of the feedstock. Second, the energy content of a liter of ethanol is typically only two-thirds of the energy content of a liter of gasoline [43].

In order to avoid the potential negative impact of biofuels, there has been a growing interest in developing biofuels produced from non-food biomass. Feedstocks from lignocellulosic materials include cereal straw, forest residues, and purpose-grown energy crops such as vegetative grasses and short-rotation forests. These so-called "second-generation biofuels" could avoid many of the concerns facing "first-generation biofuels" and potentially offer greater cost reduction potential in the longer term [44]. Once the "second-generation biofuel" technologies are fully commercialized, it is likely they will be favored over many "first-generation biofuel" alternatives by policies designed to pursue national objectives such as environmental performance and food security.

The future of bio-energy is uncertain. In many countries biofuels cannot compete on their own with other sources of energy. They survive by receiving generous governmental subsidies, which will not last forever. In short, the rapid development of modern bio-energy worldwide clearly presents a broad range of opportunities, but it also entails many tradeoffs and risks.

1.2.6 Other Renewable Sources

The IEA's definition of renewable energy sources includes energy generated from solar, wind, biomass, the renewable fraction of municipal waste, and geothermal sources, hydropower, ocean tidal and wave resources, and biofuels [45]. Recently there has been growing global interest in developing these renewable sources for at least two reasons. First, these sources provide an alternative to dependence on foreign supplies of fossil fuels. Usually, these alternatives are indigenous. They also contribute to the diversification of the energy mix. In short they enhance national and global energy security. Equally important, most renewable sources are environmentally friendly. They produce very little pollution. Indeed, the renewed interest in renewable sources is largely driven by mounting concern over climate change.

Despite these advantages, the share of renewable sources in world total primary energy supplies is currently very small. However, prospects for renewable energy "have never looked better" [46]. From 2008 to 2030, wind, solar, geothermal, tide and wave energy are together projected to grow faster than any other source of energy worldwide, at an average rate of 7.2% per year [47]. The evolution of the economic potential of renewable sources over the coming decades will depend both on their technological development and on cost in relation to competing conventional energy technologies.

Renewable energy systems are diverse – each type has its own unique characteristics. Solar power offers some substantial advantages over other energy sources. Solar generating facilities are most productive in the middle of the day, when demand for electricity typically is at its peak. Unlike fossil-fuel-fired generating capacity they produce no toxic emissions and unlike nuclear plants they leave no radioactive waste. Rooftop solar panels can be installed in homes and businesses, reducing the need for centralized power plants and transmission lines. And, of course, the sun's rays are free and available in infinite quantity. Heat storage and/or fossil-fuel backup may help fully cover the mid-peak demand during a few hours after sunset. While round-the-clock operation is technically possible, industrial heat storage options are currently not economically feasible. Although the costs of converting sunlight into usable power have dropped in recent decades, generating electricity from conventional power sources (i.e., coal or natural gas) is still cheaper. Government tax incentives are closing the gap in many countries [48]. Solar power has usually been thought of as a way of supplying electricity or heating water to a single building. But in several countries (Spain, Portugal, Australia, and the United States among others) solar power plants capable of powering thousands of homes have been built [49].

Wind power has been used for a long time, but in the last few decades several countries have allocated more investments in installing wind turbines. In recent years Germany, Denmark, the United States, China, and India, among others, have increased their reliance on wind power. Wind power is directly dependent on the cube of the wind speed within the operating range. The wind blows more reliably offshore and is often stronger, making turbines sited in the sea attractive (additionally, they can also be hidden from view). But siting turbines offshore is both more difficult and more expensive [50]. Wind power can become unavailable at times of low wind speeds, but also at times of very high wind speeds when wind turbines need to be shut down in order to avoid damage to equipment.

The ocean represents four-fifths of the surface of the earth, and humankind has always been impressed with the kinetic energy contained in the moving water of the waves and tides. Still, the mechanical technology has not been demonstrated to routinely convert this immense available energy source into economic electric power. There has been very limited success with tides, which are cyclic, depending on the relative position of the moon. There has not been commercial success with waves either. Wavers are a reciprocating motion that vary greatly in height and so require considerable mechanical apparatus to convert them to the steady rotary motion needed for electric power production. In short, neither tides nor waves have the economics of very large-scale operations available to them because they are both local and cyclic [51].

Hydroelectricity is considered a renewable source because it depends on rainfall, which is a recurrent phenomenon in different seasons every year. In sites where a waterfall exists or where it can be built with the construction of a barrage, the potential energy of the falling water can be harnessed to generate electricity. The hydroelectricity score of growth is limited by the availability of suitable sites and the serious and complex environmental problems that affect many of them. There is little scope for growth in developed countries so that future expansion is most likely to take place in the developing world [52].

Geothermal energy depends on the availability of permeable hot rock and hot water. It can provide base load capacity since variability is not an issue. Near-surface geothermal heat is only accessible in limited regions worldwide. Geothermal energy is largely untapped in many areas of the world and is available in many developing economies in South and Central America, Africa, and South-East Asia [53].

Most of these renewable sources share a number of characteristics. They are more likely to develop at a local level. Unlike oil, natural gas, and coal, which are shipped all over the world, solar, wind and water power are limited in their potential to expand geographically. Most of these renewable sources supply energy intermittently. In many cases the technology is available to deal with this drawback. Still, this "irregularity" suggests that renewable sources are less reliable than conventional fuels. Further, the costs to develop most of the renewable sources are still high. In recent years technological advances have substantially lowered costs. Still, most of these sources cannot compete with fossil fuels on their own and depend heavily on government subsidies. These characteristics should not discourage the development of renewable sources. Technological, environmental, financial, and political incentives are making renewable energy more attractive. In short, renewable energy is very promising but has some way to go to realize its full potential.

This brief survey of sources of energy highlights the advantages and disadvantages of each fuel. Political, economic, geological, and environmental considerations shape each consumer's choice of energy mix. These choices are also influenced by the availability of adequate investments, by decision-makers' willingness to welcome foreign investments into their energy sectors, and by geopolitical dynamics.

1.2.7 Investment

Energy security depends on sufficient levels of investment in mineral development, generation capacity, and infrastructure to meet demand as it grows. Fossil fuels suffer from natural decline. The rate of natural decline varies from one region to another and from one fuel to another. Energy analysts estimate that the global average rate of natural decline of oil fields is around 10% [54]. This means a need for more investment to combat natural decline and to explore and develop new fields to meet growing demand.

The amount of capital that national and international energy companies and governments are willing to allocate is conditioned, at least, by two factors – namely, economic and political factors. Generally, high energy prices mean more capital accumulation in the producers' coffers. Part of these financial resources is invested to expand production and make more profit. On the other hand, low energy prices mean less money available for investment. For example, systematic under-investment characterized the oil industry for most of the 1990s.

The decision to invest in one country or one sector is usually driven by a number of considerations. One of them is the investment environment. Capital flows will not materialize without a reasonable and stable investment framework, timely decision-making by governments, and open markets. How much a government is willing to partner with a private or foreign company varies from one region to another. Ironically, for a long time most Middle Eastern oil producers (the largest in the world) did not welcome private/foreign investment in their energy sector (particularly oil) on the grounds that it is a strategic sector. Saudi Arabia, the world's largest oil producer and exporter, rejects any foreign investment in upstream projects (exploration and development). In the 1990s, the kingdom reluctantly allowed some foreign companies to explore for natural gas, but not oil. Other major Middle Eastern producers such as Kuwait and Iran impose very strict conditions on foreign participation. Thus, most capital goes to exploring and developing high-cost reserves due to limitations on international oil companies' access to the cheapest resources.

The IEA projections imply a need for a cumulative investment in the upstream oil and gas sector of around $8.4 trillion (in year 2007 dollars) over 2007–2030, or $350 billion per year on average [55]. This necessary investment is not likely to materialize without an agreement between energy producers and international companies on the appropriate investment environment.

1.2.8 Resource Nationalism

The re-emergence of a phenomenon known as resource nationalism has further complicated the investment environment and altered the dynamics of the relationship between national oil companies (NOCs) and international oil companies (IOCs) from cooperation to confrontation. The term is assumed to have two components: limiting the operations of private IOCs and asserting greater national control over natural resource development. Another driver is the perception among ordinary people that they have seen little or no benefit from the extraction of "their" oil and minerals. Finally, there is also an important ideological component to the phenomenon, strongly linked to the perceived role of the state in the operation of the national economy [56].

The first NOC was created in Austria in 1908 [57]. Prior to the 1970s there were only two major incidents of successful oil nationalization, the first following the Bolshevik Revolution of 1917 in Russia and the second in 1938 in Mexico. During the 1970s, however, virtually all of the oil resources outside of North America passed from international petroleum companies to the governments of the oil producers. A clear extension of resource nationalism was control over oil prices by the oil exporting countries. Thus, the politics of resource nationalism were integral to the politics of the so-called new international economic order, a Third World movement whose aim was to correct the perceived structural inequities inherent in the global balance of power [58].

In the twenty-first century the relationship between NOCs and IOCs is ambivalent. The former hold nearly 80% of global reserves of oil and dominate the world's oil production [59]. Analysts at the James A. Baker III Institute for Public Policy at Rice University project that NOCs will control a greater proportion of future oil supplies over the next two decades [60]. In addition to making a profit, the NOCs serve the strategic interests of their governments. Thus, the rising role of the NOCs suggests a growing influence of geopolitical considerations at the expense of commercial interests.

1.2.9 Geo-policy

Energy and energy products are considered both commercial and strategic commodities. Almost all human activities depend on different forms of energy, most obviously mobility. Accordingly, decisions on production, prices, trade, and investment are not exclusively subject to supply and demand equilibrium. Rather, political and strategic considerations shape these decisions substantially.

Given this overlap between economic interests and strategic considerations, energy security is challenged by a number of geopolitical threats:

- Internal instability, civil wars, and sectarian or ethnic violence have disturbed production in producing countries. The ongoing ethnic strife in Nigeria and sectarian conflict in Iraq following the demise of Saddam Hussein's regime are cases in point.
- Terrorist attacks on energy infrastructure threaten the free flow of energy shipments and require huge expense to protect energy installations. Attacks on Saudi Arabia's main refineries and Iraq's oil pipelines have been reported.
- Politically motivated suspension of oil or natural gas supplies by a major exporter can threaten energy security in several receiving countries. In the last few years Russia stopped the flow of its natural gas to Ukraine. The reasons are a combination of disagreement over prices and Moscow's displeasure at political developments in Kiev. These interruptions have had a broad impact on several European countries since a substantial proportion of Russian gas to Europe transits Ukraine.
- Economic sanctions against a major producing country can deprive it of badly needed foreign investment and deal a heavy blow to its hydrocarbon production. The severe reduction in Libya's oil production for most of the 1990s can be largely explained by the international sanctions that Tripoli was under. Similarly, US sanctions on Iran since 1979 have deprived the country from fully utilizing its energy potential. Before the 1979 Revolution, Iran's oil production reached 6 million b/d. Despite massive efforts to update and modernize the country's energy infrastructure in the last three decades, Tehran's oil production has never reached the pre-Revolution level.
- War between energy producers can lead to the destruction of their energy infrastructure and installations and to a surge in prices. The Iran–Iraq War (1980–1988) and the First Gulf War (1990–1991) took Iranian, Iraqi, and Kuwaiti production off the market and caused turmoil in the global energy markets.
- Territorial disputes can increase tension between the concerned parties and slow down the full development and utilization of their hydrocarbon deposits. The five countries that share the Caspian Sea (Azerbaijan, Iran, Kazakhstan, Russia, and Turkmenistan) have failed to agree on how to divide the Basin between them. This failure has not stopped the IOCs from investing in the region, but the absence of a legal framework has complicated the speedy utilization of the Caspian oil and gas deposits.

This list is not exclusive, rather these examples illustrate some of the major internal and external challenges that threaten energy security. Another major challenge is the security of shipping lanes. Energy trade depends on the security of the thousands of tankers which carry millions of tons of oil, natural gas, and coal from producing regions to consuming ones. These tankers cross narrow and strategic straits. In 2007, total world oil production amounted to approximately 85 million b/d [61], and around 55 million b/d or 64% of the world's total oil flows through these fixed maritime routes [62]. The international energy market is dependent upon reliable transport. The blockage of a chokepoint, even temporarily, can lead to substantial increases in total energy costs. In addition, chokepoints leave oil tankers vulnerable to theft from pirates, terrorist attack, and political unrest in the form of wars or hostilities as well as shipping accidents which can lead to disastrous oil spills.

The Strait of Hormuz connects the Persian Gulf with the Gulf of Oman and the Arabian Sea and is considered the most important oil chokepoint due to its daily oil flow of 16.5–17 million barrels (2008), which is roughly 40% of all seaborne traded oil (or 20% of oil traded worldwide) [63]. Closure of the Strait of Hormuz would require the use of longer alternate routes at increased transportation costs.

The Strait of Malacca links the Indian Ocean to the South China Sea and Pacific Ocean and is the shortest sea route between Persian Gulf suppliers and the Asian markets – notably China, Japan, South Korea, and the Pacific Rim. Oil shipments through the Strait of Malacca supply China and Indonesia, two of the world's most populous nations. It is the key chokepoint in Asia with an estimated 15 million b/d flow (2008) [63].

Other important transit chokepoints include the Suez Canal, which connects the Red Sea with the Mediterranean Sea, and Bab El-Mandab, a strategic link between the Mediterranean Sea and Indian Ocean. The Turkish Straits (Bosporus and Dardanelles) connect the Black Sea with the Sea of Marmara and the latter with the Aegean and Mediterranean Seas respectively. Finally, the Panama Canal connects the Pacific Ocean with the Caribbean Sea and Atlantic Ocean.

In addition to tankers crossing maritime routes, transit pipelines are used to ship oil and natural gas to consumers. A transit pipeline is defined as an oil or gas pipeline which crosses another sovereign territory to get its throughput to market. Normally there are at least three parties to any transit pipeline agreement, each located in different sovereign entities. These are the producer of the oil or gas, the consumer, and the third party – the transit country (there can be more than one transit country). Any reading of the history of transit oil and gas pipelines suggests a tendency to produce conflict and disagreement. Paul Stevens explains these conflicts as follows: (a) different parties with different interests are involved in the pipeline project; (b) there is no overarching legal jurisdiction to police and regulate activities and contracts; and (c) the projects attract profit and rent to be shared between the various parties [64].

To sum up, energy security does not reside in a realm of its own, but is part of the larger pattern of relations among nations. How those relations go will do much to determine how secure we are when it comes to energy. Furthermore, energy security is no longer the sole purview of any individual state. Increasingly its challenge is met at the level of transborder, regional, and international interactions.

1.3 Conclusion

Energy markets are rapidly evolving to meet growing and changing needs all over the world. Energy security is certain to remain a major concern for policy-makers and analysts for a long time. In closing, several conclusions need to be highlighted. First, in recent years, nuclear power and renewable sources have received increasing attention. These fuels have great potential and are likely to increase their contribution to the global energy mix. However, most energy analysts and organizations project that oil, coal, and natural gas will continue to dominate energy markets.

Second, despite legitimate concerns about the availability of enough energy resources to meet the world's growing demand, it seems that the world's combined fuel deposits are adequate to meet this challenge in the foreseeable future. Stated differently, geology poses less of a challenge to energy security than geo-policy. What happens "above ground" is more likely to shape global energy markets than what is available "underground." These above-ground challenges include relations between producers and consumers, investment policies, and environmental issues, among others. This is why an interdisciplinary approach is needed to address these challenges.

Third, within this context, the concept of energy security should reflect the interests of all concerned parties (consumers and producers, national and international companies, and environmentalists, among others). The concept should also include the whole energy chain (exploration, development, production, transportation, refining, and final consumption). Finally, energy security should not be seen in zero-sum terms where one party's gains are another party's losses. Energy could be, and indeed in many cases is, a win–win situation. Creating greater certainty and stability would benefit all parties. Cooperation, not confrontation, is a key strategy in pursuing energy security.

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