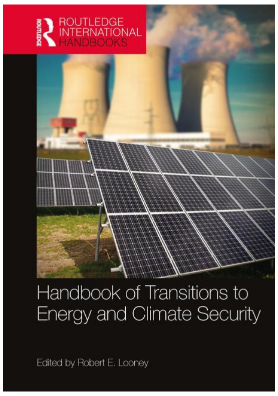

Handbook of Transitions to Energy and Climate Security

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Evolving factors affecting energy security

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Evolving factors affecting energy security

Marcus D. King

Introduction

The international energy system is in a state of constant change. However some global trends are discernible. These trends must be understood and taken into account as policymakers strive to balance considerations of energy security, climate security and economic competitiveness into policy frameworks that are, in most nations, increasingly designed to attain reductions in greenhouse gas emissions. Policies developed in response to intensified efforts to reduce greenhouse gases will have both positive and negative implications for global economies and populations.

Basic assumptions about energy supply and demand are shifting. Global markets are changing as North American oil and gas production has risen exponentially based on new discoveries and technologies. These factors as well as melting ice due to climate change have enabled the exploitation of vast hydrocarbon reserves in the Arctic if market forces are favorable. Population growth and rising consumer expectations are driving steady increases in energy demand in all sectors but the rate of this growth has been tempered by stagnant economies in several regions.

Trends in the geopolitics of energy are raising a number of concerns. Political turmoil in the oil supplying regions of the Middle East and Africa, Russian political threats to cut energy supplies to European markets, and growing instability around energy supply “chokepoints” are high on this list. These developments provide cause for many nations to reconsider their global alliances and strategies to insure energy security.

Physical threats to energy infrastructure, both natural and manmade, are another important factor. Vulnerabilities in energy production, trade and distribution systems are increasingly apparent. While the number of proven cyber-attacks against energy infrastructure remains low, growing adversarial capabilities present rising challenges for governments and corporations. In the natural world, slow-onset environmental changes such as water scarcity caused by droughts and the depletion of mineral resources may be overshadowed by the shock of extreme weather events but these threats are just as credible.

The development of clean energy technologies is an avenue that national governments can pursue in order to build economic competitiveness while advancing the other primary goals of energy and climate security. Rapid changes in clean energy technologies in such areas as nuclear energy, cleaner fuels and the possibility of climate geoengineering will no doubt alter the impacts of the other trends identified in this chapter. However, breakthroughs in these areas carry the potential to bring enormous benefits to mankind and insure energy security.

Energy security is an umbrella term that covers many concerns linking energy, economic growth and political power. Individual definitions vary widely based on whether security is perceived from an economic, social welfare, national security, sustainability or political viewpoint.[1]

Economists emphasize energy supply over other elements of a definition. A comprehensive economic definition is the availability of adequate, reliable, and affordable energy.[2] Winzer refers to this condition as "energy supply continuity."[3] Historically, the avoidance of oil supply disruptions and the resultant economic effects of price volatility are significant because oil price shocks frequently precede economic recessions.[4] Similarly, access to new energy reserves, the ability to develop new infrastructure, and stable investment regimes are the critical factors in insuring energy security for energy supply companies. At the microeconomic level, energy security is the ability of households and businesses to accommodate disruptions of supplies in energy markets.[5]

For national policymakers, energy security definitions focus on the risks of supply disruption and the security of infrastructure from terrorism, wars or natural disasters. Defense and security institutions offer more securitized definitions. For example, the Center for a New American Security, a U.S. think tank, deemphasizes price and affordability altogether, defining energy security as maintaining energy supplies that are "geopolitically reliable, and physically secure."[6] Others recognize that energy security contains a component of environmental sustainability or sustainable development.[7]

A more comprehensive definition of energy security takes human security into account. Sovacool observes that scholars can "no longer … envision and practice energy security as merely direct national control over energy supply, and it now necessitates careful cultivation of respect for human rights and the preservation of natural ecosystems along with keeping prices low and fuel supplies abundant."[8] Finally, Ladislaw and Nakano build on previous definitions by also taking political and social acceptability factors into consideration.[9] Trends that influence all of the dimensions of energy security identified herein will be discussed in the following sections.

Supply, demand and energy security

Global energy supply

The world hydrocarbon market has experienced a revolution in the availability of previously unexploited hydrocarbon resources. Historically, hydrocarbon resources were under the control of a few states centered in the Middle East. The geographic distribution of major energy resource has now shifted. The United States has become the world's leading producer of oil and natural gas combined,[10] having surpassed Russia in 2013. According to one scenario, North America became a net exporter of oil and gas in 2015, and will account for 66% of net global export growth from 2015–2035.[11] North America switches from importing 6% of its energy in 2013 to exporting 19% by 2035. Accordingly, oil accounts for over 60% of that reversal and the region becomes a net oil exporter in 2018.[12]

The current surge in hydrocarbon production is generally confined to North America and is due to a revolution in the accessibility of oil and natural gas from shale, sandstone, carbonate, and other tight geologic formations. U.S. and Canadian producers have taken advantage of efficient, cost-effective drilling and production techniques. These include horizontal drilling and fracking, a technique that uses the injection of high-pressure fluid to release gas and oil from rock formations.[13]

This surge in supply is expected to intensify because significant North American liquefied natural gas (LNG) exports are bottlenecked due to the fact that there is now only one operable natural gas export terminal located in Alaska.[14] This terminal is used primarily for exports to Japan. However, exports will increase with the construction of new terminals. The U.S. Federal Energy Regulatory Commission (FERC) has approved the construction of seven additional terminals and six are under construction.[15]

The increase in U.S. and Canadian production is a swing factor that has caused disruption in the global price of oil. The price until now has been largely determined by the Organization of Petroleum Exporting Countries (OPEC). OPEC's share of global oil output dropped from 42% in 2008 to 39% in 2014.[16] Therefore, the balance between OPEC and non-OPEC countries that governed the oil market for the last thirty years has been suspended, at least for now, and there is no guarantee that OPEC will regain its market share.

In general terms, increased U.S. natural gas supply will put downward pressure on gas prices in Europe and Asia in the years ahead.[17] Relatively inexpensive oil and gas supply has challenged Europe's green energy security policy agenda that promotes the development of more expensive renewable energy technologies over gas for energy production. However, although North American output has substantially increased, the unpredictability of energy suppliers in Russia, the Middle East and North Africa will continue to be a source of price instability in Europe in the shorter term, complicating the picture for energy planners.[18]

The rise in U.S. energy production is considerable and it has boosted energy security. Increased production is attributable in part to unique factors such as financiers with a tolerance for risk, a property rights regime that allowed for ownership of underground reserves and highly-developed network of delivery infrastructure. No country other than Canada enjoys such an industrial environment at this time.[19] In addition to a greater availability of fossil fuels, the diversity of U.S. energy supply has also increased. Solar electricity generation has increased 20-fold since 2008, and electricity generation from wind has more than tripled.[20] However, to maintain this energy security status U.S. policymakers will have to strike a balance between legitimate concerns over damage to the environment and safety risks associated with expanded energy production (such as those raised by opponents of hydraulic fracking) and securing the full economic benefits of the energy boom.

An expansion of oil and gas availability in the Arctic also signals a rise in the global supply of energy. The melting of the Arctic ice sheet, accelerated by climate change, is expected to increase access to hydrocarbon reserves. The Arctic contains about 22% of the total undiscovered, technically recoverable resources in the world. More specifically, the Arctic accounts for about 13% of the undiscovered oil, 30% of the undiscovered natural gas, and 20% of the undiscovered natural gas liquids.[21]

The path of Arctic energy extraction is difficult to predict. In 2015, after years of preparation, two major oil companies, Shell and Statoil announced plans to abandon drilling based on economic and regulatory concerns.[22] The profit margin of Arctic oil has diminished due to low world prices and reductions in demand.

Global energy demand

Based on current growth trends, world population will continue to grow until at least 2050. Projections indicate that the estimated world population of approximately 7.3 billion in 2016 could reach 9 billion by 2040.[23] Most of this population growth will occur in the developing world. Regional population growth signals an overall increase in global energy demand.

Differences in regional demand for energy and the type of energy that will be required for economic growth can be explained by variations in geographic distribution of population, income growth, and technological conditions.[24] While little population growth is expected in the global North, substantial population and income growth is expected in more southerly latitudes. Electricity demand for cooling would increase in these regions.[25]

According to scenarios developed by the International Energy Agency (IEA), growth in energy demand will be driven primarily by India, China, and countries in Africa, the Middle East and Southeast Asia. The IEA is linked to the Organization for Economic Cooperation and Development (OECD), a membership group consisting of developed and emerging economies. Under the IEA scenario, during the period from 2015–2040, non-OECD countries account together for all the increase in global energy use, as demographic and structural economic trends, allied with greater efficiency, reduce collective consumption in OECD countries. These declines are led by the European Union (-15% over the period to 2040), Japan (-12%) and the United States (-3%).[26]

Energy demand in the power sector is likely to correlate more closely with demographic change. India will be responsible for a large amount of increased demand for energy with population and incomes on the rise; an additional 315 million people are anticipated to be living in India's cities by 2040. India is expected to make three-quarters of its energy investments in the power sector, which needs to almost quadruple in size to keep up with projected electricity demand.[27] In contrast, the share of primary energy devoted to power generation in North America is expected to increase just slightly over a similar period.[28]

Liquid fuels have been an exception to the overall trend in demand growth. During the last two years, increased global supply of oil and gas has been accompanied by a decline in demand for these commodities. The recent downward demand shift for natural gas was driven by slowing global economic growth, specifically in key developing economies of China, India, and Brazil.[29] The demand drop in China is the most dramatic.[30] Other influential factors include greater energy efficiency in vehicles in response to previously high oil prices and reductions in the cost of some renewable energy technologies.[31]

The drop in global liquid fuel demand may be ephemeral, however. The faster that oil prices drop, the faster they might rebound and become an engine for economic growth. The U.S. Energy Information Administration (USEIA), estimates in their "reference case" projection scenario that world liquid fuels consumption will increase by more than one-third by 2040.[32]

Evolving energy geopolitics

In addition to increased energy security, the U.S. appears to be a geopolitical winner. The shale gas and tight oil revolution has done much to counter a global narrative that the U.S. is a geopolitical power in decline. The huge boom in U.S. oil and gas production, combined with the country's other enduring sources of military, economic and cultural strength should enhance U.S. power. Likewise, the geopolitical influences of some countries that have used their oil revenues in ways that are inimical to U.S. interests are likely to shrink. Iran, for example, has the highest fiscal breakeven price for oil at $150 per barrel. As of October 2015, the current price per barrel of oil stood at $45.25.[33]

While the revolution in shale oil and tight gas production began in North America, it is slowly spreading to other parts of the world.[34] Production increases in nations outside of North America are beginning to expand their geopolitical influence. Increases in production elsewhere in the Americas such as Brazil and Argentina, could help ensure increased availability of liquid fuels supplies for many years.[35] Likewise, there is potential for recent legislative changes in

Mexico will reverse that country's recent trend of slowly declining oil production.[36] Despite the existence of substantial reserves, timetables for production in Europe are longer. Experts estimate that if European nations were interested in exploiting domestic gas reserves, it could take 15 years to assess these reserves, build infrastructure and produce gas.[37]

Russia's position of influence appears stable, especially in Europe. Although an increase in global oil and gas supply will likely diminish its stature, with rich resources and new investment in exploration, Russia is likely to remain an important liquid fuels producer in the future.[38] At present, much of Russia's oil production comes from fields in the country's West Siberian Basin; however, interest is shifting toward undeveloped resources in East Siberia, the Russian Arctic, the northern Caspian Sea, and Sakhalin Island.[39] Previous Russian threats to cut off gas supplies have placed European economies dependent on Russian gas supply in a vulnerable position.[40]

Rising global political instability

Instability in developing nations can affect energy systems in a variety of ways as institutions become less functional. However, interruption of energy supply is the threat in which policy-makers and security organizations from more developed nations are most interested.[41]

Growing political instability often linked to internal violence, among major oil exporters such as Venezuela, Nigeria, and countries in the Middle East and North Africa (MENA) has wider geopolitical implications.[42] Within Africa, the situation in Nigeria is precarious. Since the 1990s, rebel groups in southern Nigeria such as the Movement for the Emancipation of the Niger Delta (MEND), where the majority of oil infrastructure is located, have reacted to political and income disparities by pirating oil, sabotaging oil equipment, and holding oil company employees hostage.[43] This insurgency demonstrates that energy systems can be attractive targets for attack when conflict ignites.

Other potential hot spots for supply disruptions are in areas adjacent to sensitive maritime chokepoints for oil transport. Protection of maritime transportation is essential to maintaining access to energy supplies. Approximately 84% of the world's maritime crude oil and petroleum trade flow through the top seven chokepoints: Strait of Hormuz, Strait of Malacca, Suez Canal and Suez-Mediterranean Pipeline (SUMED), Bab al-Mandeb, Danish Straits, Turkish Straits and the Panama Canal.[44]

Indonesia has experienced some political instability in the province of Aceh, home to an active insurgency for several decades. If the central government continues to prove unable to respond to disasters, separatists might renew piracy in the Straits.[45] Pirates based in Somalia have occasionally intercepted oil tankers in the Arabian Sea. From 2008–2012, actual and attempted robberies against ships in this region outnumbered those in the Straits of Malacca by 447 to 9.[46] The total amount of oil seized has been small and it is generally returned to the world market after the shippers have paid ransom.[47]

A gradual opening of the Arctic due to melting icepack and the potential exploitation of vast energy resources will also have geopolitical consequences. Between 2008 and 2011, a spate of major policy announcements and actions by nations with territorial claims focused on re-militarizing the region. These actions suggest the possibility of emerging interstate competition for control and access to the region's resources.[48]

Evolving environmental factors

As energy systems evolve, the way they are interacting with the natural world is changing. Environmental change and growing energy scarcity are the forces that will constrain energy resources.

Climate change

The direct physical impacts of climate change, such as increased frequency and severity of storms, heat waves, and droughts will impact energy security in a number of direct and consequential ways. Climate change is the "actor" that may 1) create second-order effects that may exacerbate social instability and disrupt energy systems; 2) directly impact energy supply and/or systems.[49] Climate change's direct impacts on energy systems and resources are likely to have more negative than positive impacts on the global supply of energy.[50] Accounting for regional variations, climate change will likely cause a net increase in global energy demand.[51]

Growing water scarcity

Several issues converging at the nexus of water and energy have gained substantial and growing attention. Climate change is one of several factors, including overwithdrawal contributing to global water scarcity. Maintaining adequate water supply in the face of climate change is a major emerging issue. In many regions, climate change is likely to reduce precipitation, increase surface water evaporation, and decrease river flows.[52]

The scale of water use for energy production is tremendous. The energy sector accounts for about 15% of world water withdrawal, a figure second only to agriculture. This percentage of total water withdrawals is projected to increase by 20% between 2010 and 2035.[53]

All power generation technologies use at least some water.[54] Nuclear reactors and fossil fuel electric generation plants use water for functions including cooling, steam generation, and waste disposal. In the U.S., for example, a nuclear plant was forced to shut down one of its reactors in 2012 because the ocean water used to cool emergency diesel generators and other safety-related equipment was too hot.[55]

Although it is perhaps not as intuitive as other effects, solar power generation also faces limitations due to water scarcity. Concentrated solar power is a promising technique involving the deployment of hundreds or thousands of revolving mirrors used to focus solar energy on a column of liquid, which in turn generates steam for electric turbines. These large-scale facilities require as much, or more, water for cooling as thermoelectric power plants.[56]

Growing water scarcity will certainly diminish hydroelectric generation capacity in many nations, posing the risk of plant shutdowns with associated impacts on local and regional economic activity.[57] Hydropower is by far the largest of renewable energy sources in the current global electricity mix.[58] The southeastern United States, Europe, eastern China, southern Africa, and southern Australia are particularly vulnerable.[59] Brazil, the world's second-largest producer of hydroelectricity after China, has been the victim of a prolonged and brutal drought.[60] Dwindling Himalayan glaciers may also decrease the potential for hydroelectric generation in China and in South and Southeast Asia.

Water shortages will put particular stress on China's energy sector where hydroelectric capacity has already been in decline for several years due to droughts.[61] Hydropower is China's second-largest energy source after coal. The country's installed hydropower capacity is set to rise to 350 gigawatts (GW) by 2020, up from 300 GW in 2015.[62] China is home to half the world's 80,000 dams, more than the United States, Brazil, and Canada combined.[63]

In the face of these environmental conditions, Chinese policymakers are likely to increase reliance on coal-fired power plants, the cheapest alternative to hydropower for energy generation. Existing carbon capture and storage (CCS) technologies can substantially decrease coal plant emissions. However, adding CCS technologies to coal plants would more than double their water consumption.[64]

Every energy sector requires water. In the transportation sector, biofuels and synthetic fuels production competes with other water uses, including agriculture and human consumption. Extractive technologies such as hydraulic fracturing are also a very water intensive process because the fluids for oil and gas recovery are largely comprised of water. Many of the world's unexploited oil and gas reserves are located in arid zones.[65] In sum, water scarcity is a key factor that will reduce options in nations working to increase energy security through the promotion of less carbon-intensive energy strategies.

Extreme weather

Taken in aggregate, a narrative over recent decades indicates a statistical trend toward more frequent and intense extreme weather events.[66] Rising frequency of heavy downpours is an expected consequence of a warming climate. Increased precipitation will have a slightly positive impact on hydroelectric potential in Asia with diverging patterns across other regions.[67] However, extreme heat waves experienced in some parts of the world decrease the efficiency of power plants during periods when electricity demand is highest, placing additional stresses on the electricity systems, including grids.[68]

Energy infrastructure is susceptible to disruption by weather conditions even in the most developed countries.[69] A blackout that crippled most of the U.S. northeast in 2003 occurred on a hot summer day when electricity demand was high and an overheated power line in a small Ohio town sagged and came into contact with a single tree.[70] This normally unremarkable incident interacted with several other power system failures to create a major regional blackout that affected 50 million people in the U.S. and Canada and caused financial losses between $4 and $10 billion in the United States.[71]

Physical and cyber threats

Although threats to energy infrastructure are global, power outages in the U.S. grid system caused by extreme weather serve as quotidian tests of the grid's resilience and regional coherence.[72] In this way, past natural events can offer insight into how the grid will react to cyber-attacks at similar energy chokepoints in the future. Because the U.S. grid is relatively regionally dispersed – it is made up of three regional systems with equipment administered by over 3,000 companies and municipalities – a high-impact cyber-attack is likely to have limited reach.[73] In 2014, the U.S. Department of Energy reported hundreds of outages caused by natural hazards and physical damage, but only three "suspected" cyber-attacks took place.[74]

At the same time, the potential for a cyber-attack to cause damage to energy equipment, with significant implications for customers, should not be understated. In the U.S., the complexity of the U.S. grid system means that there are many vulnerable crossover points.[75] The precedent set by the 2010 Stuxnet attack – the first deployment of cyber-physical weapons technology in which a computer worm caused Iranian nuclear centrifuges to spin out of control – and the increased frequency of cyber-attacks targeting energy companies in general are evidence of the changing threat landscape.[76]

The exact level of vulnerability can depend on grid architecture. The implementation of "smart grid" technology to increase economic and energy efficiency in response to climate change mitigation policy would connect homes to energy stations using Internet-based systems and could increase exposure to cyber-attack.[77] However, microgrids or localized grids can also disconnect from the traditional grid to operate autonomously and help mitigate grid disturbances to strengthen grid resilience, can play an important role in transforming the nation's electric grid and reduce the possibility of widespread damage resulting from a cyber-attack.[78]

According to Admiral Mike Rogers, director of the U.S. National Security Agency, major powers, such as China and Russia, already have the capability "to shut down, [and] forestall our ability to operate our basic infrastructure, whether it's generating power across this nation, [or] whether it's moving water and fuel."[79] Increasing robustness across the board to withstand high-risk, low-impact events is the first step to enhancing the ability to guard against anomalous events, such as cyber threats and extreme weather. Doing so in most nations will depend on the coordination of the federal government and private companies. According to Burke and Schneider, "no matter how much money a company spends on a cyber-security program, if aging equipment is not replaced, maintenance is inadequate, or there is inadequate power supply to meet consumer demand, then there is a significant vulnerability to an outage."[80] Ultimately, nations will have to learn to balance the process of infrastructure modernization, implementing systems such as the "smart grid" cyber security measures, and implementing the best strategies to maintain resilience against extreme weather.

Evolving climate change mitigation policies

Climate change mitigation is the "stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system."[81] In the coming decades, stronger policies to mitigate climate change will have a significant effect on societal norms, the cost and usage of energy, land use, and economic development strategies.

Heralded as a global achievement, on December 12, 2015, 195 countries convened the 21st Conference of the Parties (COP 21) under the aegis of the United Nations Framework Convention on Climate Change (UNFCCC). They reached a comprehensive voluntary agreement to reduce global greenhouse gas emissions with a goal of keeping temperature rise within 2 degrees Celsius.[82] Momentum leading up to the agreement reached in Paris was underscored by the presence of 150 presidents and prime ministers, the largest single day gathering of heads of state.[83] This agreement will be a key factor guiding national mitigation policies as well as international collective action to manage climate change.

The Paris Agreement articulates two long-term emissions goals. First, a peaking of emissions as soon as possible with recognition that it will take developing countries longer to reach the target and a goal of greenhouse gas neutrality (expressed as a "balance between anthropogenic emissions by sources and removal by sinks") in the second half of the century.[84]

During COP 21, national governments proposed unique greenhouse gas reduction targets known as Intended Nationally Determined Contributions (INDCs). The agreement creates a process whereby countries will submit INDCs every five years with clear expectations that they will represent a progression from previous years.

National adherence to the Paris Agreement will foreground some existing mitigation strategies and promote new approaches. A distinct feature of the Paris Agreement is that it clearly encourages voluntary contributions by developing countries. The creation of emissions targets in new countries moves countries away from the old North-South paradigm and into a paradigm of mutual dependency and creates a more complicated and dynamic climate change mitigation regime. Unlike previous agreements reached under the UNFCCC framework, the Paris Agreement includes provisions that encourage nations to take individual or collective action to utilize carbon markets.[85] Less developed nations may now choose to join carbon trading schemes, expanding those structures dramatically.

The Paris Agreement will also influence the trajectory of spending for research and development of clean energy technologies in many countries. Under the agreement, 20 nations have pledged to double their public research and development funding in clean energy under an initiative called Mission Innovation. A parallel private initiative by 28 of the world's richest private sector investors will support these public investments by providing capital for high-risk projects.[86] The agreement will open for signature in April 2016 and enter into force after 55 countries that account for at least 55% of global emissions have ratified it.[87] If states ratify the agreement quickly it could enter into force before 2020.[88]

An initiative to encourage non-state actors to enter pledges was also highly successful. Nearly 11,000 commitments from 2,250 cities, 150 regions, 2,025 companies, 424 investors and 235 civil society organizations were registered.[89] The emergence of some of these new actors will also change the nature and scope of existing climate change mitigation regimes.

Mitigation policies enacted to support the targets established by the Paris Agreement could also be strengthened by the implementation of a revised set of UN Sustainable Development Goals (SDGs). Earlier in 2015, 193 nations agreed on a revised set of goals including the achievement of universal global access to energy by 2030.[90] Specifically, the signatories agreed to: expand access to reliable and modern energy services; increase the share of renewables in the global energy mix and double the global rate of improvement in energy efficiency.

To meet the SDGs, developed nations must revise their international energy policy postures and development strategies. Like the Paris Accord, the SDGs promote increased cooperation in technology research, and development and investment in energy infrastructure in least developed countries.[91] Implementation of policies in support of the SDGs will benefit economies focused on manufacturing and diffusion of clean energy technologies.

Nuclear energy generation

Energy production and use account for around two-thirds of global GHG emissions today.[92] Considering the global emissions targets established by the Paris Agreement, nuclear energy is the only proven technology that can scale up to meet the world demand for carbon free sources,[93] but its share of global electricity generation has been declining since 1993.[94]

However, nuclear energy has great potential to improve energy security in the long run. It is expected to play an important role in the energy mix due to factors such as demand for electricity in the developing world, climate change concerns, security of energy supply and price volatility for other fuels.[95] By 2030, a low projection by IAEA indicates 17% growth in world total nuclear power capacity by 2030, while the high projection suggests as much as a 94% growth.[96] The following table demonstrates projected global growth in nuclear power. As Table 2.1 below illustrates, China and India are expected to lead the world in new reactor construction.

Nuclear power presents operational, financial, and political risks. The capital costs of new nuclear reactor construction can be astronomical. A study by the Massachusetts Institute of Technology estimates that a new nuclear plant in the U.S. would have an initial cost of $4 billion. Financing charges could add another $2 billion.[97] One company, Electricité de France estimates that the new Hinkley Point plant in the United Kingdom is expected to cost $36 billion.[98] A low price of natural gas and development of renewables would also hedge against nuclear growth.

Environmental risks are manifested in two ways. While there is widespread scientific agreement about how the waste disposal should be approached, the politics are complicated.[99] Globally, there is currently no permanent facility for the storage of high level nuclear waste.

Table 2.1 Nuclear reactors around the world

Country	*Reactors operable*	*Reactors under construction*	*Reactors planned*	*Reactors proposed*
USA	99	5	18	24
France	58	1	0	1
Japan	43	3	9	3
Russia	35	8	25	23
South Korea	25	3	8	0
China	30	24	42	136
India	21	6	24	36
Canada	19	0	2	3
UK	15	0	4	9
Ukraine	15	0	2	11
World Total	440	65	173	337

Source: World Nuclear Association (www.world-nuclear.org), as at March 2016.

Sites have been identified in Sweden and Finland, but these are projected to open only in the next decade or two.[100]

Environmental safety concerns surrounding nuclear power are considerable. The 2011 accident at the Fukushima reactor in Japan resulting from an earthquake and tsunami caused explosions and radiation release. It is the probable explanation for a significant, if possibly temporary, global slowdown of new power reactor installation.

Some civilian nuclear technologies can provide a basis for weapons development programs. Iran is one country located in a politically unstable region where attempts to build such a program have been successful.[101] These concerns are not confined to the Middle East. Every nation surrounding the volatile South China Sea that does not possess nuclear power – Vietnam, Malaysia, Indonesia, the Philippines and Singapore – is considering the acquisition of nuclear power reactors[102] presenting a regional security concern.

Advances in technology could facilitate growth in the nuclear sector. New nuclear fuel cycles and reactor technologies that address some of the concerns are under development creating hope that some of the gravest concerns can be allayed.[103] Some of the most promising technologies will be discussed later in this chapter.

Climate mitigation policy and energy security

Some long-run solutions to climate security will require higher prices for gasoline, electricity, and home heating oil[104] diminishing energy security for many consumers in the short term.[105]

Climate and energy security can be cross-compatible in the area of efficiency when these measures provide near-term cost reductions and serve to maintain or increase energy supply availability and reliability.[106] Whether energy consumption reductions can completely offset cost increases associated with more efficient technologies is situational and remains a point of contention.

There are many instances where policies designed to mitigate climate change and that promote energy security can be mutually reinforcing. In more advanced economies, energy conservation is described as a “no regrets” strategy for enhancing energy security while reducing climate change. In many cases, policies that reduce demand for energy – especially oil – through technology innovation (such as advanced alternative vehicle development) require greater energy efficiency.

One tension inherent in policies for climate change mitigation and energy security is that policies addressing each may require implementation on different timescales. Climate mitigation may phase in greenhouse gas emissions (GHG) reductions over time because climate risks evolve over decades and many of the solutions, including capital stock replacement, also require decades to implement. However, the risks associated with energy security affect national economies on daily to annual time scales.[107]

Climate policies can undermine energy security by limiting near term energy supply options. Consequently, Bordoff et al. suggest that greenhouse gas emissions reductions would be less disruptive to energy security if they were implemented only after key technological solutions, such as carbon capture and sequestration, become available for large-scale deployment.[108] This recommendation is at odds, however, with other analysts such as Yohe who argue that significant GHG emissions reductions must begin immediately to achieve any long-term climate stabilization goal at the minimum cost.[109]

Regulatory uncertainty surrounding long-term climate policies, particularly in major greenhouse gas emitter nations, has also had an indirect negative impact on energy security. In the United States, this uncertainty has caused power companies to delay capital investment decisions, such as building new natural gas, nuclear or renewable generation facilities that would lower carbon emissions and diversify the fuel mix.[110] Construction of new coal-fired plants is also on hold, causing generation capacities to lag demand growth in some cases while the economics of renewable and nuclear energy plant construction remains hazy, also based, in part, on regulatory factors.

Greenhouse gas mitigation policies can also carry consequences for human security. Twenty% of all greenhouse gas emissions come from deforestation and forest degradation.[111] Organizations such as the World Bank and the United Nations Environment Programme (UNEP) have implemented policies known as Reducing Emissions from Deforestation and Forest Degradation (REDD) to stimulate forest management and pay for ecosystem services. Disputes over land rights have an impact on the livelihoods of people who depend on the forests.[112]

Evolving disruptive energy technologies

Economic security through technology development

National governments are pursuing policies designed to promote the development of clean energy technology with the goal of achieving energy security, mitigating the worst impacts of climate change and increasing economic security. It is predictable that investments by governments' research institutions and corporations are increasing the likelihood of breakthroughs in clean energy technology across the spectrum of energy sectors including extraction, efficiency, storage, and generation.

However new energy technologies must traverse several stages within an innovation and development pipeline before they can be commercialized. Generally, these stages can be described as research, development, demonstration, and deployment. The transition between stages can be difficult because each stage has varying financial, intellectual, and facility requirements. For example, while start-up funding may be drawn from government sources, latter stages of clean energy technology development require large infusions of corporate and venture capital.

Despite these barriers to market entry, economic security is a key motivation for national governments to promote the development of innovative clean energy technologies.[113] Motivated by concerns about energy security and competitiveness, several European countries have established themselves as leaders in this area. Spain, Germany, the U.K., and Denmark are the leaders among them. Spain, home to some of the world's most successful renewable energy companies, has an installed renewable energy generation capacity of more than 30%.[114] Likewise, Germany has focused its large industrial sector on the manufacture of wind and solar technologies. More than a quarter of its electricity generation comes from wind, solar and other renewable sources.[115]

In addition to these national-level measures, the European Union has established an overarching framework of policies and institutions, such as the Europe-wide carbon trading market, that have encouraged the development of clean energy technology. Policies that encourage the adoption of renewable technology at the household level have successfully incentivized the deployment of clean energy technology across Europe.[116]

China has also positioned itself as a world leader in clean energy technology development and production. China is the world's largest manufacturer of wind turbines and solar panels.[117] Chinese success can be partially attributed to inexpensive manufacturing conditions coupled with protectionist policies which have helped to gain maximum market leverage from clean energy and build the Chinese manufacturing base to the detriment of its competitors.[118]

The United Arab Emirates (UAE) is a perhaps unexpected example of a country that sees the huge potential in investing in clean energy technology. Despite its status as an OPEC nation and possessing nearly 10% of the world's proven oil reserves, it has launched initiatives to position itself as a world leader in renewable energy technology.[119] Oil titan Saudi Arabia is also seeking to become a global solar power.[120]

The following section reviews key emerging technologies in each energy sector. The common characteristic of these technologies is their trending and relatively high capacity to spark breakthroughs in coordinated attempts to reduce global emissions and promote energy security through continued access to reliable energy supplies. Some of the benefits and barriers to development of these technologies are discussed in detail below.

Extractive technologies

Switching to natural gas as an energy generation choice is an option for greenhouse gas mitigation because it is less carbon-intensive than coal. Hydraulic fracturing (fracking) is the dominant technique that has allowed producers to tap into large tight oil, shale oil, and shale gas deposits.

An international debate about fracking's environmental consequences has emerged as the use of this technique spreads from North America to other regions. Concerns surfaced by this debate are a key factor preventing fracking from reaching its full technological potential. First, water contamination and the possibility of methane emissions are the main environmental concerns.[121] These risks to water resources include fear of contamination of surface and groundwater during site preparation, drilling, well completion, and operation.[122] Second, methane release during the fracking process is another major issue. In the most extreme scenario, the total amount of GHG emissions saved by extracting clean natural gas from fracking at a particular site would be offset by "fugitive" GHG emissions from methane released during drilling, completion, and operation of an unconventional well including flaring at the wellhead.[123]

While preventing methane release still remains a challenge, much of the current research is focused on better ways to address fracking's effects on water supplies including through the use of waste water or minewater, liquids other than water, compressed gasses, potentially including carbon dioxide.[124]

Energy generation technology

Renewable power

Solar and wind are the fastest growing sources of renewable energy by an order of magnitude.[125] More energy from the sun reaches earth in one hour than all of the energy consumed on our planet for one entire year.[126]

The emergence of solar and wind technologies is enabled by convergence of complementary rising technologies such as battery storage, big data and smart grids. They have the most disruptive potential.[127]

Costs of wind and solar energy have declined steadily since the 1980s but they have fallen the most dramatically in the last decade, causing a vast expansion in global deployment. This advantage marked a corresponding increase in global wind power with an expansion from 48GW in 2004 to 318GW by the end of 2013 and a growth in photovoltaic solar capacity from 2.6GW to 139GW in the same time period. In some areas, wind and solar are now cost competitive with coal and natural gas much of the time.

Innovations such as more efficient solar collection panels continue to reduce the cost and increase the attractiveness of this generation option. Wind power is a relatively mature technology. But incremental improvements in components including turbines, towers, blades and materials, and reduced construction and maintenance costs are also likely to increase wind power's economic competitiveness.[128]

Microgrids also enable the integration of growing deployments of renewable sources of energy such as solar and wind. In addition, the use of local sources of energy to serve local loads helps reduce energy losses in transmission and distribution, further increasing efficiency of the electric delivery system.[129]

Despite these cost advantages energy output is limited to when the sun is shining or the wind is blowing so these technologies are impeded by their intermittent nature. Improved energy storage technologies are needed to overcome these challenges.

Energy storage

Energy storage is perhaps the decisive enabling factor in determining the rate of development for renewable energy. Lithium-ion batteries are the most successful storage devices to be developed in the last 20 years.[130] This is the type of battery most often found in new electric and hybrid cars that are appearing on the market.

In 2014, the electric car company Tesla announced plans to build a $5 billion factory in Nevada, U.S.A., that will produce batteries that can hold up to 50 gigawatt hours of electricity by 2020. This figure represents more than the total amount of electricity produced globally in 2013.[131]

Lithium batteries have a tendency to overheat but gradual improvements in cost, storage density and manufacturing economies of scale mean it's still the best choice for many applications. A limiting factor is that lithium deposits are concentrated in the hands of a few countries. Other advanced automotive technologies require significant quantities of other rare earth minerals; at least 50% are concentrated in China which has exerted geopolitical leverage by threatening to cut off supplies swapping one dependency (foreign oil) for another (foreign rare earth minerals), with significant implications for the geopolitical landscape.[132]

Nuclear fusion and small modular nuclear reactors

The promise of fusion is very high because it can produce theoretically unlimited power without any carbon emissions and very little radioactive waste. Although there are some radioactive waste products from fusion they will become inert within a few hundred years, as opposed to the thousands of years that waste from fission reactors stays dangerous.[133] Further, fusion power plants cannot go critical, produce runaway reactions or a meltdown in the way that nuclear fission does.[134]

In 2014, an American company, Lockheed Martin, conducted the first fusion experiment that yielded more energy than was needed to start it. The company announced in 2014 that they could deliver a prototype fusion reactor in five years.[135] Other international consortia in the U.S., Europe, Russia and Japan have conducted experiments with fusion.[136]

There has been a substantial level of investment in this technology. In May 2015, ARPA-E, an American research agency affiliated with the Department of Energy, invested $30 million in entrepreneurial companies. There has been $450 million in investment in new private schemes according to the British Atomic Energy Authority.[137] In the past few years there has also been a sprinkling of entrepreneurs conducting experiments.

Fusion research has been conducted for 60 years and estimates of when hydrogen reactors will be available vary but some fall within the next few decades. ITER, formerly known as the International Thermonuclear Experimental Reactor, is a long standing fusion project in France directed by international consortia. According to some estimates, it will be ready for operation in 2027 at more than twice the original price tag.[138] If all the technical and design refinements in successive experimental reactors go according to plan, it is expected that the very first fusion power plants could be producing electricity for the grid by 2045–2050.[139]

Multiple studies have been conducted in recent years to assess the features and benefits of smaller-sized reactor designs suitable for global deployment. Small Modular Reactors (SMRs) are an emerging technology that has potential advantages over larger plants because they provide owners more flexibility in financing, siting, sizing, and end-use applications.

Nuclear power plants traditionally have a large capital cost and SMRs can reduce an owner's initial capital outlay or investment because of the lower plant capital cost. These reactors can be built in a controlled factory setting and installed module by module, reducing the initial investment costs.[140] This is especially important for developing economies or smaller markets which typically have limited availability of capital funds.[141]

While some countries can accommodate large plants (>1000 MWe), smaller sized SMRs can provide power where large plants are not needed or that may not have the necessary infrastructure to support large power generation units including smaller electrical markets, isolated areas, smaller grids, or restricted water or acreage sites.[142]

Small reactors are generally classified as producing 300MWe or less. Four reactors meeting these criteria are now operational in China, India, Pakistan and Russia but they are not necessarily modular in design.[143] To fully realize all of the noted benefits of SMRs, additional research will be necessary to resolve challenges introduced by differences in the designs, technologies, and operational characteristics relative to traditional reactors.

Climate change mitigation technologies

Carbon capture and storage (CCS)

Carbon capture and storage (CCS) is the integrated process of capturing carbon dioxide (CO_2) from power generation or industrial activities, then storing (sequestering) it to prevent its release into the atmosphere.[144]

There is a lack of widespread commercial deployment of CCS due in part to the inherent weakness in establishing plant sites where CO_2 storage is available and economical.[145] Lewis observes that proposals to inject CO_2 into the oceans or deep underground geological formations are problematic because oceans are already experiencing issues with large harmful concentrations of acid and the risk of leakage associated with the use of underground formations is high.[146]

Despite these challenges, CCS technology has undisputed potential to serve as a key component of a carbon mitigation portfolio for the electricity, petrochemical and other industries. Moreover, there are numerous studies that have concluded that in the long-term CCS can be a cost effective measure to reduce global CO_2 emissions.[147]

CCS projects are capital intensive so they are caught in a classic policy dilemma. While some governments view CCS as a low carbon option, without favorable government regulations and or strong financial incentives to significantly reduce CO_2 emissions there is little or no incentive for the private sector to develop and deploy CCS technology.[148]

Climate geoengineering

Broadly, geoengineering is an attempt to change the earth's climate to support human life. The U.S. House of Representatives Committee on Science and Technology defines geoengineering as "the deliberate and large-scale modification of the earth's climate systems for purposes of counteracting and mitigating anthropogenic climate change."[149] Mankind's scientific knowledge surrounding the possible effects of geo-engineering is small but this approach might become more desirable as the established mitigation options for keeping warming of the climate system within the range of two degrees seem unreachable over time. Current attempts to achieve geoengineering follow two basic approaches: solar radiation management (SRM) through blocking sunlight to lower global temperatures and/or removing carbon dioxide (CDR) from the earth's atmosphere to allow heat to pass back through and escape to outer space.[150]

Geoengineering carries significant ecological and political risks so widespread implementation of the various technologies under research and discussion may be a risky gambit. The negative consequences could be very similar to those of climate change itself, such as the creation of weather systems that benefit some nations at the expense of others.

Furthermore, a systematic assessment of potential security risks posed by climate engineering does not exist. Existing carbon removal approaches such as the United Nations REDD program involve planting and cultivating more trees and have the potential to cause conflicts over land-use and require water in large quantities. Thus climate engineering could redistribute climate security risks and add new kinds of risk.[151]

Therefore, a troubling aspect of geoengineering is that current deployment would take place in the absence of governance or regulatory structure. There is no treaty or international body with a sufficiently large mandate to regulate all proposed climate engineering measures.[152]

Transportation Sector

Today, transport-related emissions account for over 20% of global energy-related CO_2 emissions and are set to increase without the strong uptake of alternative fuel vehicles.[153] The vast majority of the world's energy for transportation still comes from fossil fuels and this trend is expected to continue to 2035 and beyond (Institute for Energy Research, "BP Energy Outlook to 2035," February 26, 2015).[154]

Electric vehicles

Electric vehicles are already commercially available but the cost of such vehicles is high. Designing smaller more powerful batteries is the key challenge. Recharging at a massive scale puts pressure on the energy grid. Electric vehicle production has a range of possible negative impacts on the environment largely emanating from the vehicle supply chain.[155]

The industry has set ambitious targets. One car company, Toyota, is aiming to sell nearly zero regular gasoline vehicles by 2050, only hybrid fuel cell-driven models. The automaker is pushing to reduce average emissions from cars by 90% by about 2050, compared with 2010 levels.[156]

Hydrogen fuel cells are a transportation technology that is commercially available but in small numbers and at a high cost. Since they're powered entirely by electricity, fuel cell vehicles are considered electric vehicles ("EVs"). Unlike other EVs, full cell vehicles' range and refueling processes are comparable to conventional cars and trucks. The weight and design of fuel tanks and the lack of a hydrogen fuel delivery infrastructure inhibits rapid development of this technology at this time.[157]

All electric vehicles face a number of challenges related to cost, refueling infrastructure and customer preferences.[158] Electric vehicles will continue to face competition from other vehicle technologies, including diesels, grid-independent gasoline-electric hybrids, flexible fuel vehicles and more efficient conventional gasoline vehicles, all of which are likely to become more fuel-efficient in the next 20 years.[159]

Fuel technologies

Overreliance on the single commodity of oil in the transportation sector has been an Achilles heel for many countries' national and energy security due to price volatility and uncertainty that can effect investment decisions.[160] In recognition of this, countries have moved toward two options. One is to move toward cleaner fuels within the suite of fossil based options and the other is to move toward non-fossil fuel based sources. Biofuels are a non-fossil option that have been produced and consumed for many years as additives and more recently as stand-alone options.

In 2008, biofuels accounted for less than two% of the world's transportation fuel but that amount is growing rapidly.[161] Biofuels generally emit much lower levels of CO_2 than fossil fuels. This relative advantage is especially pronounced in the case of cellulosic biofuel which is produced from wood, grasses, or the inedible parts of plants and advanced biofuels such as those derived from algae.[162]

The key problem with biofuels globally is the scarcity of potentially productive land that is not already dedicated to food or livestock cultivation. Therefore cellulose-based biofuel derived from grasses and crop residue affect food security. Algae-based biofuel is potential alternative technology although it is unproven at commercial scale. However, it would likewise not diminish food security. In some countries such as Brazil, clearing the forests to provide source material can result in the release of more greenhouse gases emissions than were abated through their use.

A desire to reduce reliance on foreign oil and take advantage of abundant coal reserves has led some countries to explore coal-to-liquid fuel conversion processes (CTL). Emissions from these fuels exceed those of fuels obtained from crude oil by a factor of two.[163] While the technology is proven and commercially operative, the costs of new CTL fuel F-T plants are very high though lower than source material in natural gas. However, the production of these fuels does not contribute to GHG emissions reduction, unless CO_2 sequestration or processing is possible.[164]

Simultaneous technological breakthroughs in the extraction, generation, mitigation and transportation sectors are extremely unlikely. However, a breakthrough in one sector will change the overall energy supply and demand equation in unpredictable ways. These changes will be, on balance, beneficial to both the environment and mankind if well-informed policies are established to exploit the most positive aspects of these changes.

Conclusion

In the coming decades, national policymakers will strive to address a security trilemma: how to maintain energy security, addresses concerns over climate sustainability, and balancce economic competitiveness.

This decision must be made in the context of global trends identified in this chapter including: growth in the supply of fossil fuels coinciding with a rising awareness of their harmful effect; reduced global energy dependence on OPEC and rising instability in oil producing regions; environmental impacts of climate change and extreme weather; physical impacts of infrastructure vulnerability and the likely advent of disruptive technologies.

In 2015, nearly every nation on the globe committed to the Paris Agreement on Climate Change and the UN Sustainable Development Goals. Collective adherence to these agreements would signal global transitions toward a carbon-free future. It is clear that some technologies are poised to enable this transition. In the energy generation sector, nuclear energy is the only proven technology that can scale up to meet the world demand for carbon free sources at this time. Incremental improvements in lithium-ion batteries hold the greatest promise to improve energy storage capacity that will in turn enable more rapid development of renewable energy. Geoengineering of the climate holds great promise in the area of climate mitigation but substantial technical and regulatory issues highlight potential unintended consequences of this option. Anticipated policy decisions supporting additional research, development and deployment of these and other technologies will increase the potential for "breakthroughs" that profoundly affect global energy use. Policies that manage and exploit these opportunities can create win-win-win solutions to the policy trilemma.

Globalization will insure that no country can remain unaffected by the evolving trends outlined in this chapter. It is equally inevitable that events we cannot identify or even envision will intervene to influence the challenging choices framed by the security trilemma.

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