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Energy Security and Renewable Energy: A Geopolitical Perspective

John A. Paravantis and Nikoletta Kontoulis

Abstract

This chapter examines the role of renewable energy in shaping energy security against the backdrop of global geopolitical, socioeconomic, and technological uncertainties. The evolving definition of energy security during the twentieth and early twenty-first centuries is discussed initially. The dimensions, components, and metrics of energy security are reviewed, including the 4A definition of energy security that comprises physical availability; economic affordability; accessibility from a sociopolitical standpoint; and environmental acceptability. A novel energy security index is proposed, with the following components: physical availability; technology development; economic affordability; social accessibility; governance; unconventional threats; and natural environment. Of these, physical availability followed by technology development, economic affordability, and governance was rated as the most important, and the environment was rated as the least important by a small panel of experts. The roles of wind and solar energy are highlighted, with an emphasis on the social acceptance of renewable energy in an energy security context. Other energy security indexes are discussed, focusing on sustainability and renewable energy. Denmark, Germany, China, Russia, and the United States are examined as case studies that help understand the transition to renewable energy in the context of coopetition among states. As these countries face different political concerns, geopolitical realities, and energy security issues, they consider different policy approaches to address them.

Keywords: energy security, renewable energy, geopolitics, energy transition, case studies

1. Introduction

Energy has been crucial for economic growth throughout human history, the “precondition of all commodities, a basic factor equal with air, water, and earth” (E. F. Schumacher, Nobel laureate economist, 1977). The International Renewable Energy Agency (IRENA) [1] underlines that fossil fuels have been the foundation of the global energy system, and their role is deeply embedded in the relations among countries and regions.

The ability of a country to access the energy resources needed to maintain its national power (without compromising foreign policy, economic, social, and environmental objectives) is referred to as energy security. Energy security is paramount to human security [2] and has become an increasingly popular concept.

There is no universal definition of energy security [3, 4], which [5] has been aptly described as “slippery” and “polysemic.” Consequently, energy security has

become an umbrella term for different policy goals [6]. This ambiguity is affirmed by many existing definitions of energy security. A few years back, Sovacool [7] reported that there were at least 45 different definitions, and Ang et al. [8] identified 83 definitions in the existing literature. In a most recent study, Matsumoto et al. [9] confirmed that there are no uniform definitions or evaluation methods for assessing energy security.

Recently, a strong interest has emerged in favor of the integration of renewable energy in the energy mix as a priority measure of addressing energy security and climate change [10]. Energy security planning is increasingly geared toward establishing a low-carbon economy and achieving climate mitigation goals [11]. Article 2 of the Paris Agreement [12] requires countries to implement their nationally determined contributions and to increase their ambitions over time, necessary for keeping the rise in global mean temperature below 2°C [13].

At a time when society is increasing its demands for an accelerated transition to a low carbon energy system, the energy data for 2018 paint a worrying picture, with both energy demand and carbon emissions growing at the fastest rates seen for years [14]. Renewables and energy efficiency offer a safe, reliable, and affordable way to achieve massive decarbonization, in line with keeping the rise in global temperatures below 2°C [15].

This is a particularly exciting time to study the renewable energy dimension of energy security: the global energy landscape is in the middle of a game-changing revolution in source rock resources; consumer countries have turned into producers; producer countries have turned into consumers; and transit countries have turned into new players. The main goal of this chapter is to shed light on the role and the impact of renewables in energy security by (a) examining how renewable energy sources enter the dimensions, components, and metrics used in measuring energy security and (b) offering case studies of countries that help shed light on the link between renewables and energy security.

The remainder of this chapter is organized as follows: Section 2 provides a backdrop by linking the concept of energy security to renewable energy; Section 3 reviews the dimensions, components, and metrics of energy security and proposes a new energy security index, having experts rate their importance, discussing the role of renewable energy, and reviewing other indexes; and finally, Section 4 presents thoughts on the perspective of selected countries on energy security. The chapter is rounded up with conclusions.

This chapter is a review that presents the results of analytical research. It includes a descriptive part (expert interviews). Numerical computations were done with Microsoft Excel, and statistical analysis and graphing were done with Minitab Version 18.

2. Energy security and renewable energy

Since the turn of the twenty-first century, climate change and its link to fossil fuels have moved to the forefront of the political discourse, engaging political and industrial actors, academic researchers, and the society [16]. This has happened against a backdrop of geopolitical turmoil caused by a series of events of energy significance including:

- the second Gulf War (March 20, 2003 to December 18, 2011);
- Hurricane Katrina that caused catastrophic damage in Louisiana and Florida and underscored the importance of black-swan type of natural disasters (August 23, 2005);

- Germany's planned energy transition (*Energiewende*), a low carbon program relying heavily on renewable energy (targets set in September 2010);
- the natural gas crises between Ukraine and Russia that lasted from 2005 to 2009 and caused significant concern in the European Union (EU);
- the Arab Spring upheaval that changed the strategic balance in the Middle East and North Africa, with indirect implications for energy and geopolitics (started on December 18, 2010);
- the Fukushima Daiichi nuclear accident in Japan, showing the importance of securing energy installations from "unthinkable" natural threats (like tsunamis and earthquakes; March 11, 2011);
- the cyberattack on 35,000 computers of Aramco (the Saudi Arabia oil company that supplied 10% of global demand for oil; August 15, 2012), 1 year after the major cyberattack on Sony that compromised the personal details of 77 million PlayStation accounts (April 17–19, 2011);
- the Tigantourine gas plant hostage crisis in Algeria (January 16–19, 2013) with 39 fatalities of expatriates, the first major terrorist strike on a big energy facility;
- the adoption of the European Union Energy Union (February 25, 2015), a project of great geopolitical scope and significance;
- the signing (July 14, 2015) and later the unraveling (May 8, 2018) of the nuclear deal between Iran, the five permanent members of the United Nations (the United States, the United Kingdom, China, Russia, and France), Germany, and the EU, aiming to limit Iran's enrichment of uranium (2015);
- the lifting of the 1975 US oil export ban (September 10, 2015); and
- the Yemeni rebel attacks on two Saudi pumping stations with armed drones, the first such terrorist attack on energy installations (May 2019).

These events led to the realization that global geopolitics may threaten energy security. In this vein, renewable energy is considered a potential game changer in energy security. **Figure 1** plots the Google trends search interest for the terms "energy importance" (blue points) and "renewable energy" (green points) with dotted (pink) vertical lines corresponding to the start date of the events of the previous list. The presence of energy security and renewable energy in Google searches is a proxy of their relative importance in the global (online) discourse. **Figure 1** helps position this importance against the backdrop of global geopolitical activity. No Google trends data are available before 2004.

Energy security reached a peak in Google search interest from 2005 to 2009, corresponding to the Russia-Ukraine gas crises; its interest has been falling since then. Renewable energy Google search interest kept rising until 2009 and then fell until 2013 and has been rising since then. Its interest was also at a peak during the Russia-Ukraine gas crises and appears to have received a boost concurrent with the discussions of the EU Energy Union; the institution and then the unraveling of the Iran nuclear deal; and the lifting of the US oil export ban. Perhaps the cyberthreats of the events of Sony and Aramco helped precipitate this increased interest in

renewable energy. As a result of these trends, renewable energy has received more Google search interest than energy security since 2015.

With the turn of the twenty-first century, the price of oil (arguably the world's most important commodity) climbed to record high and exhibited fluctuations that were difficult to predict. As depicted in **Figure 2**, a barrel of crude oil, which in average annual OPEC prices cost \$2.70 in 1973, jumped to over \$10 by 1978; further jumped and fluctuated around \$30 until 1985; fell to around \$20 or less until 1999; climbed to an unprecedented high of \$94.10 in 2008, shocking the global economy; fell to just over \$60 and climbed to a new high of \$109.45 in 2012; and fell to just over \$40 and back up to \$69.52 in 2018. In 2019, only a preliminary average annual oil price per barrel was set at the time of writing (\$64.05).

These fluctuations in the price of oil, especially the unpredictability after 2008, underscore that the world has entered a prolonged era of peak oil no matter for many decades shale oil and gas will continue to supply the world.

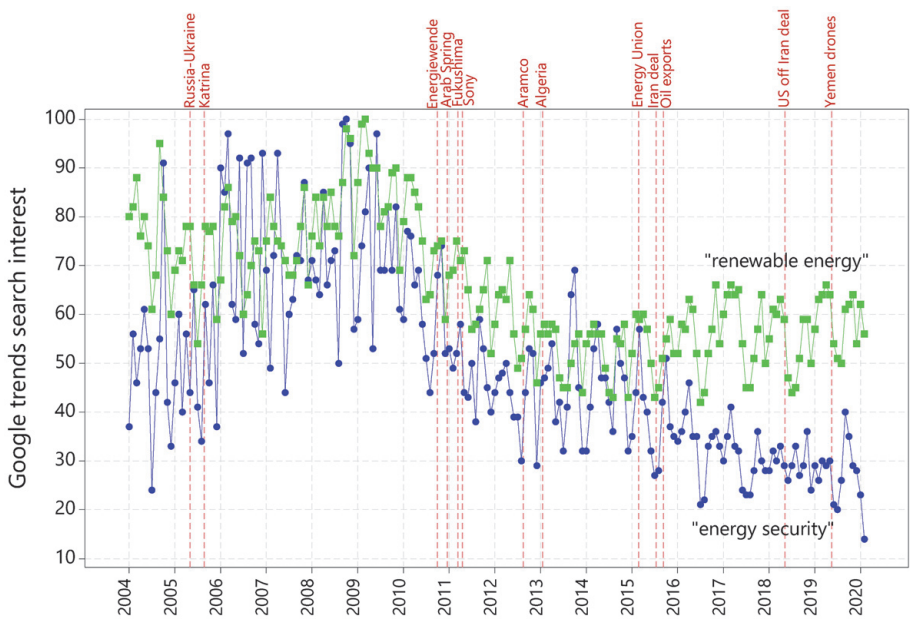


Figure 1. Google trends (<https://trends.google.com/trends/?geo=US>) search interest of energy security and renewable energy compared to global geopolitical events.

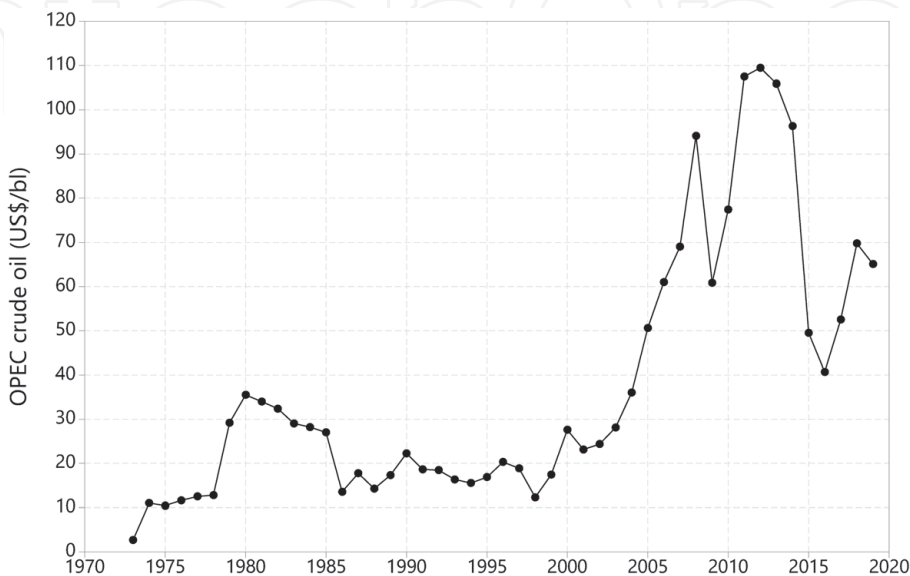


Figure 2. Average annual OPEC price of a barrel of crude oil.

The climate is a chaotic system, which, considering the Ice Ages (the last of which ended just 12,000 years ago), has exhibited wide variability in the past. Nevertheless, all evidence at this point shows that global warming and its effects will intensify during the rest of the twenty-first century, so climate change will become a more concrete and tangible target [16]. Intensifying geopolitical tensions are also likely, mainly between the United States and China (with its expanding territorial claims in southeast Asia), with other emerging powers such as India (with its own territorial issues with neighboring countries), Indonesia (with its expanding population), Brazil (host of the world's most important ecosystem), Japan, and Germany, all of which the Economist Intelligence Unit has predicted will be among the countries with the highest nominal GDP per capita by 2050.

The need to address climate change and emerging geopolitical tensions will make energy policy a field of paramount importance in international relations, with energy security its most important aspect. The need to address climate change is perceived as urgent: 2018 carbon emissions grew by 2%, which is the fastest growth for 7 years [14]. Signs of a shift away from fossil fuels have become clearer [16], for example, since the 2011 Fukushima nuclear accident, Japan and Germany have moved toward ending their dependence on nuclear energy, while the Danish parliament has decided that Denmark will be fossil fuel free by 2050.

As new energy alternatives need to be less polluting than the sources they replace, renewable energy moves naturally into center stage. Renewable energy, at least four decades old, has gained increasing currency as a conceptual alternative to centralized energy sources (e.g., coal, nuclear power), which are considered environmentally destructive and dehumanizing [17]. Yet, renewable energy is not free of impacts on natural ecosystems, economy, society, and politics:

- Wind and solar energy are dilute fuels, requiring large expanses of land. The construction of onshore wind farms in particular necessitates clearing land areas with impacts on species such as tortoises, birds, and bats.
- Wind turbines have a lifespan of around 20–26 years, after which steel, cement, and other materials used in their construction must be recycled or properly disposed of as solid waste.
- Large renewable energy projects oftentimes are opposed by society on the grounds of visual esthetics and other intrusions into the way of life.
- The intermittent nature of wind and sunlight means that the energy they capture must be stored if they are to serve as the main energy source.
- Finally, although renewable energy is becoming more inexpensive, it continues to rely on state budgets.

For the transition to renewable energy to succeed, environmental impacts must be minimized, and the profile of renewable energy projects must be made more attractive to society. Most importantly, concerns about energy security [18] and the political economy of renewables must be addressed.

The International Energy Agency (IEA) was founded in 1974, with the intention of helping countries coordinate a collective response to major disruptions in the supply of oil by the establishment of mandatory strategic petroleum reserves (<https://www.iea.org/about/ourmission>). IEA defines renewable energy as “energy derived from natural processes that are replenished at a faster rate than they are consumed.” The main renewable energy sources are wind, solar, biomass,

hydropower, geothermal, and wave. Wind and solar energy have grown at an unprecedented rate and are arguably the most significant sources, with electric utilities buying into wind power almost without hesitation. Yet, they are called variable renewable energy sources because they share a unique problematic characteristic: the amount of power they generate varies with the weather and the time of day [1].

Considering that renewable technologies have the potential to contribute to energy security while meeting the environmental objectives at the regional, national, and global levels [19], IRENA (an official United Nations observer) was founded in 2009 to serve as a platform for international cooperation on the technologies, policies, and financial know-how on renewable energy (<https://www.irena.org>). At that time, renewable energy was only a marginal contributor to global primary energy and electricity supply [20]. Now renewable energy is growing rapidly in installed capacity and investments [20]. The global awareness about renewables is shown by numbers: by the end of 2018, renewable energy targets had been adopted in 169 countries at the national, state, or provincial level. Moreover, 135 countries have power regulatory policies [21].

Decreasing the dependence on fossil fuels and increasing the amount and percentage of renewables (and nuclear energy) will help mitigate climate change [22]. Domestic renewable energy may reduce the need of countries for energy imports [20] and consequently their dependence on exporter countries [18]. So, renewable energy is considered the most secure way to minimize energy supply risks by exploiting domestically controllable energy supplies [23].

3. Defining energy security

Many researchers have investigated energy security, defining it from a variety of angles. Energy security is a contested and complex term [24], which encapsulates concepts such as security of supply, reliability of infrastructures, affordability, and environmental friendliness [25]. Energy security means different things to different countries, depending on their geographical location; their natural resource endowment; their economic disposition [26]; their status as producer/exporter, consumer/importer, or transit [27]; their vulnerability to energy supply disruptions; their political system; their ideological views and perceptions [28]; and the status of their international relations, for example, reliance on Russian gas depends on historical experiences during the Cold War [29], as cited in [27].

Examined over different historical time frames, the concept of energy security is dynamic and fluid, with evolving energy policy challenges [6, 30]. The oil crises of 1973 and 1979 transformed oil supply from a military to a socio-political and economic issue for importing countries. The gas crises of 2006 and 2009 between Russia and Ukraine raised concerns about transit countries and brought back the use of energy as a geopolitical weapon [31]. As pointed out by Cherp and Jewell [32], a classic definition of energy security has been provided by Yergin [33], who visualized energy security as the assurance of “adequate, reliable supplies of energy at reasonable prices,” adding a geopolitical component by qualifying that this assurance must be provided “in ways that do not jeopardize national values or objectives.”

The IEA, a pioneer institution in energy security and the most important multinational energy platform, defines energy security as the “uninterrupted availability of energy sources at an affordable price” and considers it to have long- and short-term aspects. The IEA has restated the definition through the years to characterize energy security as the adequate, affordable, and reliable supply of energy.

Long-term energy security relates to “timely investments to supply energy in line with economic developments and environmental needs.” Short-term energy security relates to “the ability of the energy system to react promptly to sudden changes in the supply-demand balance” [10, 34–36].

Countries have different energy security objectives depending on their role in the energy market: producer/exporter countries aim to ensure reliable demand for their commodities; consumer countries commonly aim toward diversity of energy supply, so as to minimize their dependence and maximize their security; and transit states try to make the best of their role as bridges connecting producers/exporters with their markets [26]. For consumer and transit countries, security of supply is important; for producer/exporter countries, security of demand is possibly as important as security of supply [27].

3.1 Dimensions and components of energy security

To highlight the role of renewable energy in energy security, one has to conceptualize and formulate the latter. Energy security is considered to be composed of a small number of dimensions, for example, technical, social, environmental, political, geological, and economic [37]; each dimension contains components, and each component may be measured by metrics, that is, quantitative or qualitative indicators. When all metrics, components, and dimensions are aggregated, an energy security index may be calculated based on available data.

In an extension to the original IEA definition of energy security, the Asia Pacific Energy Research Centre [4] highlighted the so-called four As of energy security: (1) availability of the supply of energy resources; (2) affordability of the price of energy resources, so that economic performance is not affected adversely; (3) accessibility to all social actors; and (4) acceptability from a sustainability standpoint. The first two As (availability and affordability) constitute the classic approach to energy security (the twentieth century), while the latter two (accessibility and acceptability) reflect contemporary environmental concerns, such as climate change, and sociopolitical issues, such as fuel poverty.

Ang et al. [8] argued that the most important dimension of energy security is availability, as this is taken into account in 99% of related studies. The term availability is also used to imply stable and uninterrupted supply of energy [38–40], while some authors use the term reliability to refer to the role of energy infrastructure [41, 42] and the production of electricity and heat [43]. As for accessibility, it has been at the center of energy security debates and policy approaches into the twenty-first century [44]. Goldthau and Sovacool [45] talked about the following three key energy challenges: energy security, energy justice, and a low carbon transition. They highlighted the need to consider energy security as a democracy issue; equity as an important aspect of accessibility; and global climate change as an important aspect of acceptability.

A similar set of four dimensions of energy security has been proposed by Sovacool and Rafey [46]: (1) availability, that is, diversifying the fuels, preparing the disruption recovery, and minimizing the dependence on foreign supplies; (2) affordability, that is, providing the affordable energy services and minimizing the price volatility; (3) efficiency and development, that is, improving the energy efficiency, altering the consumer attitudes, and developing the energy infrastructure; and (4) environmental and social stewardship, that is, protecting the natural environment, communities, and future generations.

Alhajji [47], a global energy expert, differentiated among six dimensions of energy security: economic, environmental, social, foreign policy, technical, and security. Vivoda [48] listed seven salient energy security dimensions: environment,

technology, demand side management, sociocultural or political factors, human security, international elements like geopolitics, and the formulation of energy security policy and 44 attributes of energy security. Knox-Hayes et al. [49] extracted the following dimensions of energy security: (1) availability, indicating security of supply and affordability; (2) welfare, indicating equity and environmental quality; (3) efficiency, representing various factors including low energy intensity and small-scale energy (with some overlap with welfare); (4) affordability, indicating (among other factors) price affordability and small-scale energy; (5) environment, appearing to be very similar to welfare; (6) transparency, standing for equity, transparency, and education; (7) climate, connected to global climate change and having significant overlap with welfare and environment; and (8) equity, overlapping with other dimensions.

Sovacool and Mukherjee [2] presented the following dimensions with corresponding components: (1) availability, that is, security of supply and production, dependency, and diversification; (2) affordability, that is, price stability, access and equity, decentralization, and affordability; (3) technology development and efficiency, that is, innovation and research, safety and reliability, resilience and adaptive capacity, efficiency and energy intensity, and investment and employment; (4) environmental and social sustainability, that is, land use, water, climate change, and pollution; and (5) regulation and governance, that is, governance, trade and regional interconnectivity, competition and markets, and knowledge and access to information as well. Regarding energy independence, self-sufficiency may be a more pragmatic target since even a producer/exporter country cannot really extricate itself from the global energy markets and their vulnerabilities [50].

3.2 Metrics of energy security

There is a multitude of energy security indicators: Sovacool and Mukherjee [2] assembled 320 simple indicators and 52 complex indexes of energy security. Kruyt et al. [3] differentiated among simple indicators, such as reserves-to-production ratios, import dependence, energy prices, political stability and demand-side requirements, and aggregated indices. Sovacool and Brown [51] considered energy security to be defined according to the following criteria (i.e., dimensions), which may be measured with corresponding metrics: *availability*, measured by oil and natural gas import dependence and availability of alternative fuels; *affordability*, measured by retail electricity, gasoline, and petrol prices; *energy and economic efficiency*, measured by energy intensity, electricity use per capita, and average fuel economy of passenger vehicles; and *environmental stewardship*, measured by sulfur dioxide (SO₂) and carbon dioxide (CO₂) emissions.

In a paper evaluating the energy security performance of 18 countries from 1990 to 2010, Sovacool et al. [52] presented a more detailed list of dimensions, components, and corresponding metrics, adding the dimensions of regulation and governance, measured by energy exports; competition, measured by energy subsidies per capita; and information, measured by the completeness of energy data. Ang et al. [8] confirmed governance and added other dimensions such as infrastructure and energy efficiency.

An even more detailed definition of energy security involved the following dimensions, components, and corresponding metrics [53]:

1. *Availability*, measured by security of supply, equal to $\frac{\text{total production energy}}{\text{total consumed energy}}$; self-sufficiency, equal to $\frac{\text{imported energy}}{\text{total consumed energy}}$; diversification, measured by a diversity

index such as the Shannon-Wiener; renewable energy, equal to $\frac{\text{renewable energy}}{\text{total consumed energy}}$; and technological maturity, a qualitative metric.

2. *Affordability*, measured by price stability, equal to the deviations of price about a global mean value; dependency, equal to $\frac{\text{total imported energy}}{\text{population}}$; market liquidity, a qualitative metric; decentralization, equal to $\frac{\text{total energy by distributed and small-scale generation}}{\text{total energy production}}$; electrification, equal to the percentage of population with reliable access to grid; and equity, equal to the percentage of households depending on wood, straw, and so on for cooking and heating.
3. *Accessibility*, measured by the following qualitative metrics: import stability, trade, political stability, military power, and safety and reliability, all qualitative metrics.
4. *Acceptability*, measured by the following qualitative metrics: environment, a composite of several “micro aspects” that are “measured individually”; social satisfaction, national governance, international governance, transparency, and investment and employment.

It may be concluded that renewable energy is a factor in much of the research that aims to conceptualize, define, and measure energy security.

3.3 Synthesizing an energy security index

Having reviewed the dimensions, components, metrics, and methods of energy security, a novel energy security index will now be synthesized. An effort was made to combine all the dimensions and components meaningfully, without overlap. The following seven dimensions and components are proposed:

1. *Physical availability*, the historical bedrock of energy security [3, 26, 38, 54], accounting for security of supply; self-sufficiency (affected by oil and gas import dependence and accounting for the boosting effect of renewable energy); Strategic Petroleum Reserves (SPR, acting as a buffer and a deterrent); and energy diversification (accounting for the contribution of small-scale distributed renewable energy installations).
2. *Technology development*, accounting for (state and maturity of) infrastructure, for example, matching of available oil to refinery infrastructure; energy (grid) efficiency (the “fifth fuel”); onshore and offshore wind farms; energy consumption and conservation in the building sector, transportation systems, and the industry; decentralization, that is, diffusion of small scale and prosumer systems (mostly renewable energy); and research (intensity), development, and innovation (with a sizeable portion expected to be related to renewable energy).
3. *Economic affordability*, perhaps the second most important energy security dimension historically, accounting for affordability of electricity and gasoline prices (expressed in Purchasing Power Parity); stability (i.e., lack of volatility) and predictability of prices; competition, subsidization (per capita), and profitability; energy intensity (i.e., electricity use per capita and monetary unit of GDP); and fuel economy of passenger vehicles (also related to technology).

4. *Social accessibility*, that is, social stewardship, accounting for dependency (expressed as imported energy per capita); electrification, that is, percent of the population with (reliable) access to the electricity grid (potentially improved by resorting to renewable sources); energy democracy, for example, percent of households that are fuel poor (also likely to be improved by renewables); social equity, for example, percent of households relying on traditional energy sources (such as wood) for cooking and heating; and consumer awareness, knowledge, and attitudes, for example, toward renewable energy [55, 56].
5. *Governance*, taking into account: quality of governance, measured by, for example, the Worldwide Governance Indicators (WGI) of the World Bank (<https://info.worldbank.org/governance/wgi>) that rate “voice” (i.e., citizen participation) and accountability, political stability (which may be measured by the number of years since the previous regime change) and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption (i.e., transparency and accountability, no crony capitalism); type of polity (democracy or otherwise); military power (possibly a qualitative variable); data quality and intelligence; good regulatory policies (e.g., avoiding over-regulation, setting reasonable and objective performance criteria, and avoiding picking winners and losers); and adoption of “fit” energy policies, that is, catering to all societal energy groups referred to as “tribes” [57, 58].
6. *Unconventional threats*, including asymmetric, paramilitary, or nonconventional threats to energy infrastructure, such as revolutions (e.g., Iranian revolution, Arab Spring); accidents caused by human error (likely to be less severe with renewable energy installations); durability and safety (of infrastructure, also related to technology); and terrorism incidents, including cyberwarfare (also likely to be of a less severe nature with renewables).
7. *Natural environment*, accounting for (existence of) tragedy of the commons (i.e., overexploitation of resources that are public goods, something that is irrelevant with renewable energy sources) and resource curse (i.e., the presence of abundant energy and natural resources in poor countries); (mitigation of) environmental pollution, for example, SO₂ emissions (per capita); (mitigation of) global climate change, for example, CO₂ emissions (per capita), affected very favorable with more use of renewable energy; forest cover; land use (management), probably the most important negative impact of onshore wind farms; water availability, that is, quality and quantity, (lack) of water stress and scarcity, and access to improved water quality; environmental (sustainability) management; health problems caused by environmental threats, for example, high concentration of toxic substances; and (impacts of) black-swan type of natural disasters.

How are the different dimensions of energy security perceived by different economic actors? In a paper examining seven suppositions about energy security in the United States, Sovacool [59] presented the following expert suppositions pertaining to energy security issues: (1) security of supply and trade; (2) energy democracy; (3) energy research; (4) energy efficiency; (5) affordability; (6) environmental pollution; and (7) climate change. It was concluded that the different dimensions of energy security are perceived differently by those working in different sectors of the economy:

- The private sector considered the following four energy security dimensions to be the most important (with a rating over 4.5 of 5): (1) conducting research and development on new and innovative energy technologies; (2) providing available and clean water; (3) minimizing the destruction of forests and the degradation of land and soil; and (4) minimizing air pollution.
- Among government occupations, more (i.e., eight) dimensions were rated over 4.5, including the four of the private sector plus the following: (5) reducing greenhouse gas emissions; (6) minimizing the impact of climate change; (7) assuring equitable access to energy services to all of its citizens; and (8) informing consumers and promoting social and community education about energy issues.
- With universities, even more dimensions were rated over 4.5, including the four of the private sector plus the following: (5) reducing greenhouse gas emissions; (6) minimizing the impact of climate change; (7) informing consumers and promoting social and community education about energy issues; (8) assuring equitable access to energy services to all citizens; (9) ensuring transparency and participation in energy permitting, siting, and decision making; and (10) having low energy intensity.
- The nonprofit sector rated the following dimensions over 4.5: (1) providing available and clean water; (2) minimizing air pollution; (3) conducting research and development on new and innovative energy technologies; (4) minimizing the destruction of forests and the degradation of land and soil; (5) reducing greenhouse gas emissions; (6) minimizing the impact of climate change; (7) informing consumers and promoting social and community education about energy issues; (8) assuring equitable access to energy services to all citizens; (9) ensuring transparency and participation in energy permitting, siting, and decision making; and (10) having a secure supply of coal, gas, oil, and/or uranium.
- Finally, those working in intergovernmental occupations rated the first two dimensions of the private sector and the following dimensions with a score over 4.5: (3) minimizing air pollution; (4) having a secure supply of coal, gas, oil, and/or uranium; (5) promoting trade in energy products, technologies, and exports; (6) reducing greenhouse gas emissions; (7) informing consumers and promoting social and community education about energy issues; (8) assuring equitable access to energy services to all citizens; and (9) having low energy intensity.

How are the dimensions of energy security covered by the research literature? In a paper examining 40 years of energy security trends, Brown et al. [60] found that 91 peer-reviewed academic articles covered the dimensions of energy security differently. In particular, availability was covered by 82% of the examined articles; affordability by 51% of the articles; energy and economic efficiency by 34% of the articles; and environmental stewardship by 26% of the articles. As to the precise nature of these dimensions of energy security, a Factor Analysis carried out by the authors concluded that: availability was mostly a function of oil import dependence, road fuel intensity, and natural gas import dependence (in decreasing order of importance); affordability was a function of electricity and gasoline retail prices; energy and economic efficiency were a function of electricity use per capita and

energy per GDP intensity; and environmental stewardship was a function of CO₂ and SO₂ emissions.

To get an idea about the relative importance of the proposed seven dimensions of energy security, expert interviews were used as in other sources [7, 61]. A small panel of engineering, economic, and geopolitical energy experts was selected, including junior and senior academic faculties (with experience in energy, environment, transportation, and geopolitics) and senior professionals (with experience in environment and water management). One of the authors was included in the panel of experts interviewed [62]. The interviews contained a brief semi-structured part (the results of which are reported in this chapter) and a longer structured part (which is not reported here). During the semi-structured part, the experts were asked to (1) rate the importance of the seven dimensions of energy security and (2) give their opinion on the way the dimensions were defined. Input received during this phase was used to improve the scope of the dimensions and clarify the definitions. Although these expert ratings reflect the perspective of Greece at the time of writing, they are interesting.

Ratings were on a scale from 1 to 10. The experts' average ratings of the importance of each energy security dimension are shown in **Figure 3**. Physical availability was deemed to be the most important dimension (in accordance with its extensive coverage in the research literature), receiving an average rating of 8.8 (of 10). Technology development, economic affordability, and governance were next, with an average importance of 8. Social accessibility and unconventional threats received an average rating of 6.8. Finally, the natural environment was considered the least important dimension (the panel did not include experts working in the nonprofit sector), with an average rating of 5.8.

Some further interview findings were as follows:

- Most experts tended to rate dimensions nearer their discipline as more important, reflecting a form of cognitive bias.
- A couple of experts thought that there was a little overlap among some of the dimensions but could not suggest ways of overcoming it.

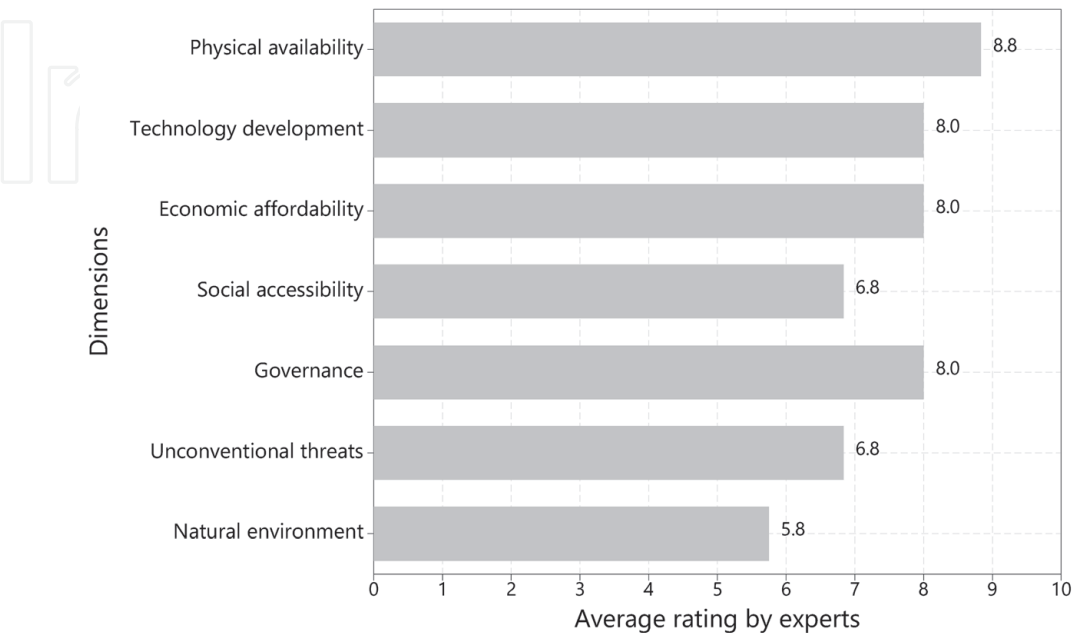


Figure 3.
Average expert rating of the importance of the dimensions of energy security.

- One expert (with intelligence background) argued that data quality and intelligence should be a separate dimension.
- There was uncertainty as to whether the impact of conventional warfare should be included in one of the existing dimensions or create an additional war dimension; the authors decided that conflict (especially war) is accounted indirectly through its impacts on almost all dimensions.

The experts were also asked to rate the importance of the dimensions of energy security at historical milestones that correspond to major geopolitical events. The more recent events were mentioned in the beginning of Section 2 of this chapter. Based on these ratings, weighted averages for the overall importance of energy security at each historical milestone were calculated. These are plotted in **Figure 4**.

In the eyes of energy experts reflecting the perspective of Greece, the importance of energy security has been increasing since the beginning of the twentieth century. Its highest ratings have appeared since 2010. This increase in the ratings of the importance of energy security is concurrent with the increased presence of renewable energy in the global online discourse (**Figure 1**). The potential role of renewable energy in energy security has never appeared more important than now.

3.3.1 The role of renewable energy in the dimensions of energy security

Although renewable energy has a much better greenhouse gas emission profile, it has environmental impacts like any other technology. Wind and solar energy are dilute fuels, requiring large expanses of land. The construction of onshore wind

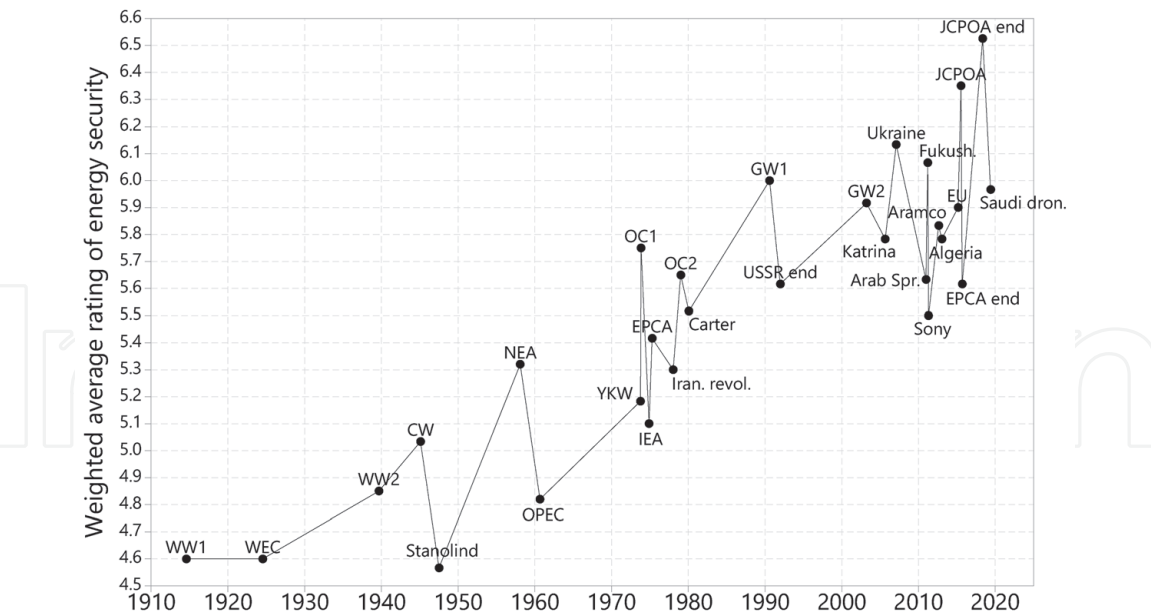


Figure 4. Weighted average expert rating of the importance of energy security (WW1: First World War; WEC: Foundation of World Energy Council; WW2: Second World War; CW: Start of Cold War; Stanolind: first fracturing experiment; NEA: Foundation of European Nuclear Energy Agency; OPEC: Foundation of Organization of Petroleum Exporting Countries; YKW: Yom Kippur Arab-Israeli War; OC1: first oil crisis; IEA: Establishment of International Energy Agency; EPCA: Institution of US Oil Export Ban; Iran revol: Iranian revolution; OC2: second oil crisis; Carter: Carter Doctrine (on protection of Persian gulf by the United States); GW1: First Gulf War; USSR end: End of Cold War; GW2: Second Gulf War; Katrina: Hurricane Katrina; Ukraine: Start of Russia-Ukraine gas crises; Arab Spr.: Arab spring; Fukush.: Fukushima nuclear accident; Sony: cyberattack on Sony; Aramco: Cyberattack on Aramco; Algeria: gas plant hostage crisis in Algeria; EU: EU energy union; JCPOA: Institution of Iran Nuclear Deal; EPCA end: Lifting of US Oil Export Ban; JCPOA end: US withdrawal from Iran nuclear deal; Saudi dron.: Yemen drone attack).

farms necessitates clearing land areas with impacts on species such as tortoises, birds, and bats. The intermittent nature of wind and sunlight means that the energy they capture must be stored if they are to serve as the main energy source. Wind turbines have a lifespan of around 20–26 years, after which steel, cement, and other materials used in their construction must be recycled or properly disposed of. These impacts mean that the participation of renewable energy in the energy mix of a country creates negative environmental impacts. These may be partially offset by the positive environmental impact of the reduction in fossil fuel usage.

Looking back at the dimensions of energy security proposed by Sovacool and Rafey [46], the components of fuel diversification, disruption recovery, minimization of dependence on foreign supplies, minimization of price volatility, and support of sustainability (although with the introduction of aforementioned environmental impacts) are all served by the use of renewable energy for electricity production. Renewable energy improves the outlook of at least three of the four dimensions of energy security defined in that work.

Recalling the definition of energy security by Knox-Hayes et al. [49], it is argued that (further to the obvious connection of renewable energy to availability) the components of environmental quality (especially climate change) and small-scale energy production are improved by the use of renewable energy.

Turning to Sovacool and Mukherjee's work [2], the following components of security of supply and production should be favorably affected by renewable energy: dependency and diversification; price stability (regardless of the level of prices); decentralization and affordability (achieved with distributed small-scale installations); innovation and research (inherent in renewable energy); investment and employment (as new jobs are created in the renewable energy industry); environmental quality, especially climate change (with the aforementioned negative impacts of renewable energy); and trade and regional interconnectivity (e.g., with onshore wind farms and distributed small-scale systems). Renewable energy probably provides the best opportunity for a country to become more independent of the vulnerabilities of global energy markets and approach the goal of energy self-sufficiency [50] irrespective of its endowment in fossil fuel resources or its access to expensive nuclear energy technology.

Considering Ren and Sovacool's detailed presentation of an energy security index [53], renewable energy entered the dimensions of availability, as the percentage it represents of the total consumed energy; affordability, influencing the total energy produced by distributed and small-scale generation (a characteristic of renewable installations); accessibility, by improving the outlook of safety and reliability (as a secondary source); and acceptability, by helping with investment and employment.

The social acceptability of renewable energy has been reviewed by Stigka et al. [55] with empirical research carried out in a later work [56]. The socioeconomic and environmental disadvantages of renewable energy were discussed, and the 2014 renewable energy performance was presented for the EU countries, with Norway, Sweden, Latvia, Finland, Austria, Portugal, and Denmark having high renewable energy usage and being near their targets [55]. The same source also points out that social actors including local communities, local agencies, investors, nongovernmental organizations (NGOs), and local information networks are involved in renewable energy projects. Opposition to projects is not uncommon, per the NIMBY (not in my back yard) phenomenon, which led the authors to review the following barriers to renewable energy projects:

- economic and institutional factors, such as economic conditions in a region, issues with public or private ownership, lack of financial incentives, high investment

costs (compared to fossil fuel alternatives), inefficiencies in the existing legal framework, complex licensing procedures, and bureaucratic problems;

- technical and planning factors, such as local geography and geomorphology, issues with the process of selecting an appropriate site (especially related to its previous usage) and planning problems;
- environmental and quality of life issues, such as landscape deterioration, visual intrusion, noise pollution and vibrations (related to the distance of residents from the renewable energy installations), disruption of nearby ecosystems, and impacts on the quality of life in the area; and
- factors related to public perceptions, such as lack of information or knowledge of renewable energy technologies, mistrust (which anxiety intensifying with ignorance), lack of impartiality, and suspicion toward investors.

The latter empirical research [56] found out that income and awareness of renewables are strong determinants of the willingness to accept renewable energy. Although esthetics could be more of a problem near tourist destinations, where economic, social, and cultural factors become involved [55], it was found that considerations related to tourism were low in the list of factors affecting the willingness to pay for renewable energy projects [56]. Renewable energy instigates the fear of uncontrolled development profits at the expense of the public good. So, steps must be taken for renewable energy to be accepted by local communities [55]. Education and the realization of positive impacts on the local economy may help in this direction.

3.4 Other energy security indexes

The literature on energy security indexes offers an insight into how the effects of energy security on the economy, society, and the environment are mediated directly or indirectly by renewable energy [38, 52, 63–65]. This section helps put the proposed energy security index in perspective.

Various studies [2, 34, 52, 66] have proposed a wide variety of energy security indexes, either to compare performance among countries or to track changes in a country's performance over time. There are indicators based on the perspective of the user [54] and others who link the concept of energy security with model-based scenario analyses in the context of addressing policy issues related to affordable energy and climate change [3].

The following are some well cited energy security index studies.

- Radovanović et al. [66] applied principal component analysis to assess the impact of individual indicators on an energy security index. They found energy intensity, GDP per capita, and carbon intensity to have the greatest impact on energy security.
- The *Vulnerability Index* [67] is a composite indicator, which considers five indicators: energy intensity; energy import dependency; ratio of energy-related carbon emissions to the total primary energy supply (TPES); electricity supply vulnerability; and lack of diversity in transport fuels [66].
- The six-factor *Risky External Energy Supply* [64] is entirely supply oriented and considers solely the level of diversification, with an emphasis on the assessment of transport safety of energy generating products [66].

- The *Aggregated Energy Security Performance Indicator* (AESPI) [68] has been developed by considering 25 individual indicators representing social, economic, and environmental dimensions. The indicator ranges from 0 to 10 and requires time series data for its estimation. AESPI helps assess the past energy security status of a country; it also helps evaluate the impacts of energy policies and plans on future energy security.
- The *Socioeconomic Energy Risk* is a composite index that considers the following indicators: energy source diversification, energy resource availability and feasibility, energy intensity, energy transport, energy dependence, political stability, market liquidity, and the GDP [66].
- The *US Energy Security Risk Index* [69] is a complex composite indicator obtained based on 83 individual indicators assessing geopolitical indicators, economic development, environmental concerns, and reliability [66].
- The concept of the “energy trilemma” is an attempt to balance the trade-offs among three major energy goals: energy security, economic competitiveness, and environmental sustainability [8]. The dimensions of energy trilemma are defined by the World Energy Council (WEC) [42] as: (a) energy security, that is, effective management of primary energy supply from domestic and external sources, reliability of energy infrastructure, and ability of energy providers to meet current and future demands; (b) energy equity, that is, accessibility and affordability of energy supply across the population; and (c) environmental sustainability, which encompasses the achievement of supply and demand-side energy efficiency, along with development of energy supply from renewable and other low-carbon sources. Related index efforts include the *Energy Architecture Performance Index* (EAPI), which was proposed in 2010 by the World Economic Forum (WEF) and was modified into the *Energy Sustainability Index* [70], a composite index based on a set of indicators grouped into three categories of the energy trilemma approach [66].
- Finally, the Renewable Energy Security Index (RESI) [25] is an index that assesses the impact of renewable energy technologies for electricity production. The index takes into consideration several factors based on the share of renewable energy into the electricity production mix at a national level. Decision makers are encouraged to use RESI as part of the transition from fossil-based to renewable-based power-generation technologies, as it promotes a sustainable model of electricity supply using domestic resources.

4. Perspectives on renewable energy and energy security

This section presents perspectives of specific countries toward renewable energy and energy security.

The global shift to renewable energy reflects a strengthening of the world's response to the threat of climate change. Most European countries have adopted policies toward a new energy transition with significant social, political, and economic implications. This transition to low-carbon energy is expected to alter the geopolitical landscape, shifting the dynamics between producer and consumer countries [1] and setting new energy standards for exporting countries [31]. In the words of Matsumoto and Andriosopoulos [22], “the lower the target of allowable emissions, the larger the required shifts to the energy structures will have to be.”

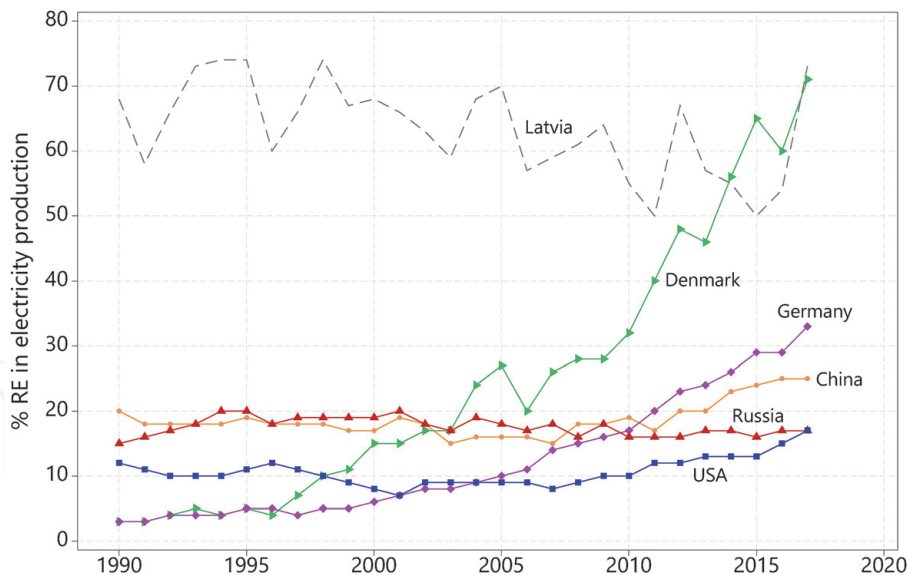


Figure 5.
Percent renewable energy in electricity production per country [71].

The energy transition is described as “a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century” [1]. The renewable energy revolution will be one of the primary aspects that characterize and underpin the low-carbon transition. Shifts from coal to natural gas and from fossil fuels to renewable (and nuclear energy) will be critical [22].

The link between energy security and renewable energy is strengthened by the diffusion of renewable energy [10]. Data from the 2018 BP Statistical Review [14] show that renewable power grew by 14.5%, somewhat below the historical average, but near the all-time high increase of 2017 in absolute energy terms. The share of renewables in power generation increased from 8.4 to 9.3%, accounting for a third of the net increase in global power generation.

In the following paragraphs, the renewable energy situation of Denmark, Germany, China, Russia, and the United States is discussed and linked to energy security. These countries include producer, consumer, and transit, with different approaches to energy security and different usages of renewable energy sources. **Figure 5** presents the percent renewable energy in electricity production of these five countries plus Latvia, a world leader in the use of renewable energy sources.

Starting from the lowest part of the graph:

- The United States has been lingering around the 10% share of renewable energy in electricity production since 1990 and appears to have achieved a small increase since 2015. Of this share of renewable energy, 55.5% comes from hydro; 26.2% from wind; 11.8% from biomass; 3.7% from geothermal; and 2.8% from solar [72].
- Russia, with its large hydropower potential, has not been very keen to develop renewable energy, focusing its attention on exploiting its natural gas resources to maintain and strengthen its position as an energy hegemon. Almost all its shares of renewable energy in electricity production come from hydro (99.6%), with 0.3% coming from geothermal, 0.03% from biomass, and 0.02 from wind [72].
- China has been producing more electricity from renewable energy than both Russia and the United States, and it has increased its corresponding share of

renewables since 2011. Of this share, 86.7% comes from hydro, 12.4% from wind, 0.6% from solar, 0.3% from biomass, and 0.02% from geothermal [72].

- While Germany started from a mere 3% of renewable energy in electricity production (like the United States), it has been increasing this 1990 share constantly, reaching a 10-fold level of 33% in 2017. Of this share, 32.1% comes from wind, 28.8% from biomass, 19.6% from hydro, 19.5% from solar, and 0.02% from geothermal [72].
- Denmark is arguably one of the most environmentally friendly energy producers in Europe, reaching a 71% share of renewable energy in electricity production in 2017. Of this share, 70.1% came from wind, 28.7% from biomass, 1% from solar, and 0.1% from hydro [72].

These five countries may be compared to Latvia, which is the undisputed historical world champion of green energy. Latvia has been producing 60–70% of its electricity from renewable energy sources (90% hydropower, 7% biomass, 3% wind, and 0.03% solar) since the 1990s [72]. Latvia is not examined in more detail because it is of less geopolitical interest than the other five countries, but it provides an interesting reference point for comparison.

Denmark, the greenest of the five countries, is indeed considered one of the most energy secure and sustainable countries among the OECD [51] and the EU27 countries [73]. Over the past 30 years, Denmark has achieved a swift decrease in its dependence on foreign energy sources from above 90% in the 1970s to practically zero and has become a net exporter of fuels and electricity [74]. At the core of Denmark's successful approach is a commitment to energy efficiency; prolonged taxes on energy fuels, electricity, and carbon dioxide; and incentives and subsidies for Combined Heat and Power (CHP) and wind turbines [75]. Denmark aims to go 100% renewable by 2050 [75, 76].

Germany, one of the largest energy importers in the EU, is in the middle of an ambitious energy transition [77]. Germany is considered the most successful country in the promotion of renewable energy [78]. In 2014, Germans had the best energy security performance among the EU countries due to the reduction of shares of oil and coal and the increase of diversification of energy imports [9]. The German energy transition (*Energiewende*) is considered the best-known renewable-based national energy policy [17]. The *Energiewende* aims to reduce the greenhouse gas emissions by 80–95% in 2050 (compared to 1990), increase the renewable share of final energy to at least 60%, and increase the renewable share of electricity demands to 80% [79]. Germany also intends to complete a nuclear phase-out by 2022 [80], a debatable move in the opinion of the authors of this chapter. Hansen et al. [79] presented a strategy for achieving 100% renewable energy for the entire German energy system and maintained that this scenario is possible with the introduction of key policies.

China is the world's largest energy consumer [14], the biggest emitter of greenhouse gases [81], the fifth largest producer of oil, the seventh largest producer of natural gas, and the largest producer of coal [82, 83]. China aims to cut the share of coal in its power mix, but coal consumption is growing, and more coal-fired power projects are under development. In fact, the percentage of fossil fuels in China's total primary energy demand is expected to exceed 90%, with coal being the main fuel source [22]. At the same time, China possesses the biggest amount of hydro resources globally, with a total theoretical hydropower potential of 694 GW [84]. By the end of 2015, China's hydro power exceeded 25% of the world's nonhydro renewable capacity, being 63.1 and 117.0% higher than the United States and

Germany, respectively [81]. Until the end of 2017, China’s installed generation capacity of renewable energy was 635 million kW, which constituted 35.7% of the total installed capacity of electric power [78]. According to the BP Statistical Review [14], in 2018, China continued to lead the way in renewable growth, accounting for 45% of the global growth in renewable power generation, more than the entire OECD combined. Wang et al. [83] discussed scenarios for a Chinese sustainable energy development, with renewable energy regarded as a key emerging industry. China is reported to plan to increase the share of nonfossil fuels in primary energy consumption to around 20% by 2030 [83]. Liu [78] calls for improvements in China’s renewable legal and policy framework, if the country is to achieve such an aim. All in all, China appears to be a reluctant and ambivalent actor in the renewable game.

Russia owns one of the largest fossil fuel resource stocks in the world and is the world’s fourth largest emitter (after China, the United States, and India). Russia has the second largest natural gas reserves and production in the world (after the United States) [14], an endowment that allows it to play a major geopolitical role, for example, as the major supplier of natural gas to most European countries. At the same time, Russia is a country of vast geographic size and variability in terrain and climate, giving it the potential to develop virtually any kind of renewable energy [85]. Russia is accelerating the deployment of solar and wind through auctions to create benefits for employment, science, technology, and energy security for isolated populations [86]. Although the country was an early leader in the technology of renewables, Russia’s strategy revolves around the development of fossil fuels and nuclear energy [87]. In 2013, the Russian government launched a Capacity-Based Renewable Energy Support Scheme (CRESS) [88]. Per CRESS implementation, a maximum installed capacity of solar, wind, and small hydro projects each year could obtain financial guarantees on Russia’s wholesale electricity market [89]. The energy security of Russia will remain linked to its natural gas deposits, while its ability to continue to supply it to the European and other markets will determine its position as an energy hegemon.

In 2018, almost half of the global raise in natural gas (5.2%) came from the United States, which (as with oil production) recorded the largest annual growth

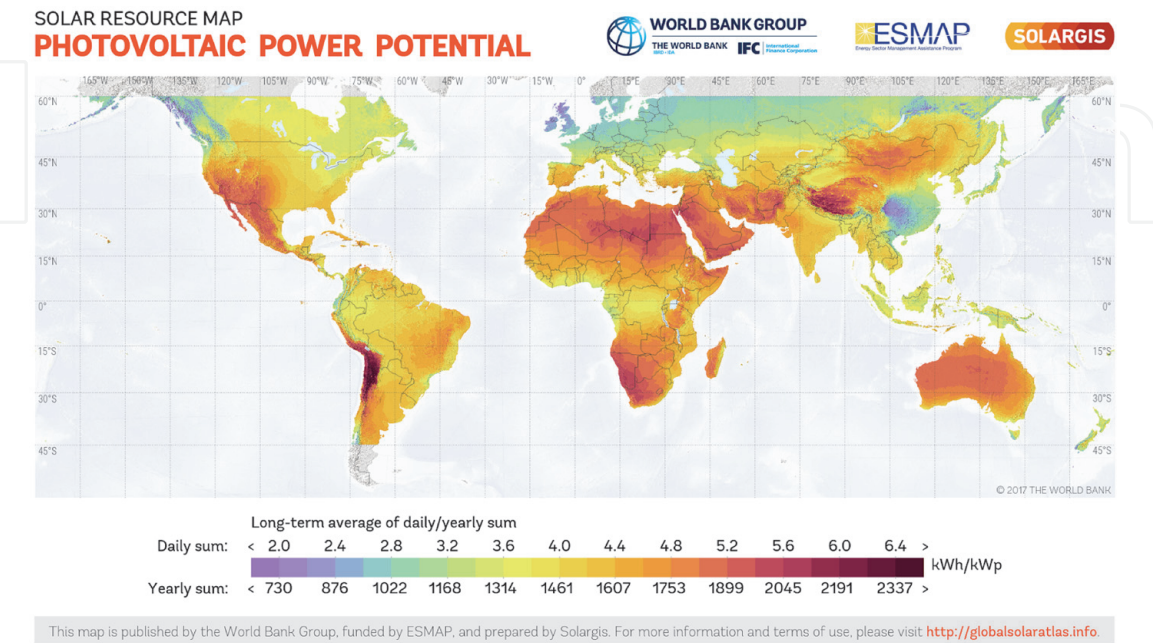


Figure 6.
Geographical distribution of photovoltaic power potential (<https://solargis.com/maps-and-gis-data/download/world>).

seen by any country in history [14]. The United States plans to achieve 80% renewable electricity by 2050 [81]. If this target is honored, it will be by actions of the states rather than at a federal level; in fact, most of the US states have started individually to enact policies that expand renewable energy capacity [90]. It seems unlikely that a federal-level renewable energy mandate will be passed soon, given the current (under President Trump) administration's quest for fossil fuel energy dominance.

Contrary to China and Russia, the EU and the United States are expected to develop a diversified energy mix with the aid of scientific and technological developments [66]. The EU will continue to improve renewables to limit its dependence on fossil fuel imports especially from Russia.

All in all, the introduction of more renewable energy sources into the energy mix of countries will influence their energy security favorably. As indicated in **Figure 6** for the case of solar energy, the global distribution of renewable energy sources is more evenly spread than fossil fuels. Furthermore, renewable energy is more amenable to distributed production, which is inherently more secure than the fossil fuel paradigm. Renewable energy will help usher an era of energy democracy, where a network of decentralized prosumer systems will play the role once dominated by large-scale power generation.

5. Conclusions

Geopolitical events in the twenty-first century have brought energy security and renewable energy in the forefront of political discourse and provided the motivation for this chapter. The energy security literature was reviewed, and a novel index of energy security was proposed. The index comprised the following dimensions: physical availability, technology development, economic affordability, social accessibility, governance, unconventional threats, and natural environment.

A small panel of academic and business experts in Greece rated physical availability as the most important and natural environment as the least important dimension of energy security. These experts thought that the importance of energy security has been increasing steadily since the beginning of the twentieth century.

Key geopolitical actors (the United States, Russia, China, Germany, and Denmark) have increased electricity production from renewable energy by a combination of different renewable sources. Despite any social acceptability issues and negative environmental impacts, renewable energy will help countries become more energy secure. At the same time, they will make themselves more resistant to geopolitical strife and more independent of the vagaries of fossil fuel markets.

As renewable energy sources are incorporated in the energy mix during the rest of the twenty-first century, the impact of geopolitical conflict on energy security will lessen. Furthermore, the energy generation industry will become more compatible with the original 4A energy security targets of accessibility and acceptability.

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