Advanced Review

Definitions and dimensions of energy security: a literature review

Abdelrahman Azzuni* and Christian Breyer

This paper sheds light on an integral aspect of the global energy system: energy security. Energy security is a universal topic that shapes policies and regulations in order to achieve higher levels of energy security and thus provides societies with a better life. Understanding the concept and its implications requires a holistic definition, but current research literature lacks a commonly accepted, precisely defined definition. Therefore, the research gap is the absence of a comprehensive definition that takes into account all energy security dimensions, and the absence of well-studied relationships between energy security and its dimensions. Taking that in mind, the gap is addressed by a systematic review of energy security definitions and by building a structural dimensionalization of energy security. Thus, this review aims to track changing definitions of energy security in modern times and formulate a concise and comprehensive definition. Furthermore, using a structural approach, 15 dimensions, and related parameters of energy security are determined and categorized to illustrate the range of issues covered by the term and to enable precise evaluation of the energy security of energy systems. The results of this review show clearly how energy security could be defined generically to account all dimensions, and show the relationships between these 15 dimensions and energy security. Understanding all dimensions of energy security provides insights for policymakers to formulate policies that account for all of these dimensions.

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INTRODUCTION

Energy security, as a universal concern,[1] has received great attention and has been the subject of many studies[2–4] within different fields of science,[5] policymaking,[6,7] national energy policies,[8] politics,[9] international relations,[10] and as a national security issue.[11] The importance of the topic stands behind its ability to shape policies and countries behavior.[12] Policymakers need to address energy security issues when regulations are made because energy security has an urgent priority.[13] As policymakers aim to ensure consumers' daily needs of energy are covered,[14] actions should be taken to ensure energy security, and thus the ultimate goal of making societies lives better is achieved. As the last end of the imposed policy in any country is to ensure people's well-being, the importance of energy security consideration is its impact on how to promote citizens' well-being.

Although the energy security concept is 'as old as fire,'[15] analysis following scientific research principles only started around 1975.[16] Ang et al.[1] state that publications on energy security were rare before 2001, but in the 21st century, the topic has emerged as one of a great importance.[17] There are many reasons for this growing interest: increased energy prices,[2] the growing dependence of industrialized economies on energy[18] as an engine for economic growth[3,19] and a driver for civilization[20] and society,[21] the global energy supply crisis,[22] climate change,[23,24] energy demand and competition,[2]

*Correspondence to: Abdelrahman.Azzuni@lut.fi

School of Energy Systems, Lappeenranta University of Technology, Lappeenranta, Finland

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political conflict,[9] social development,[16] major disruptions in oil markets[5] related to military upheavals,[25] complex global markets,[26,27] threats to the energy system,[28,29] and the mindset that considers energy security as equivalent to national security.[30] In general, energy affects every aspect of life[31] and energy is thus crucial to the survival of a functioning modern society.[3,32]

In view of the importance of the topic, there is a need for a comprehensive understanding of the term 'energy security.'[1] Only few works have attempted to clarify the nature of energy security,[2] for example, Ang et al.,[1] but most studies have been regionally focused such as Hossain et al.[33] This review article attempts to address this gap by providing an overview of energy security definitions, presenting a chronological analysis of the definitions offered, and creating a dimensionalization of energy security.

The paper is constructed as follow: First section considers drivers behind the need for a universally accepted definition of the concept. Second section provides a broad overview of key aspects: energy security definitions resulting from different standpoints[34]; evolution of definitions over time, where it is noted that in the literature there is neither good understanding[26] nor a trend analysis[1] but only a confirmation of change[35]; reasons behind the various definitions; and a proposal for a common definition for energy security.

Third section details dimensions and parameters of energy security. Energy security is a multidimensional concept[5,34] with many parameters,[26] some of which are interdependent and others are independent.[6] This dimensionalized analysis compiles dimensions of energy security established by previous research to provide a comprehensive definition and to empower assessment of the impact of the different dimensions and their interactions.

Fourth section concludes the paper and presents recommendations for utilization of the dimensional view developed in the work. In addition to being of value to the research community, the discussion in this work provides governments and policymakers with insights for energy security.

These four sections attempt to identify the gaps in previous research, and address them with novel solutions. The gaps as mentioned before are the absence of a comprehensive term for energy security,[1] the locality of previous studies,[33] and the selective dimensionalization of energy security. The novel approach of this review paper is to follow the definitions of energy security in a chronological way, in order to identify the dimensions considered in literature. Furthermore, the novel systematic construction of 15 dimensions and their parameters is not preceded before in literature. The arrangement of the dimensions and their parameters with deep understanding of the interrelationships between them and energy security is new. The novel solution provided in this review paper is the promotion of considering all of these dimensions and parameters in the decision-making and the policymaking.

Definition of Energy Security

A clear definition of energy security is critical, since energy security is a concept rather than a policy[26] or a strategy. Enhancement of energy security is a key goal of society[2,8,36–40] and sustainable energy strategies[41] because energy security is required to fulfill basic human needs.[42] Personal and national energy security are paths to achieve freedom of choice, which allows progress to self-actualization in Maslow's hierarchy of needs.[42]

However, targeting increasingly higher levels of energy security may result in overinvestment in energy security, resulting in nonoptimal use of resources that may be more valuably invested elsewhere. Consequently, the question arises: 'what is the needed level of energy security?' A wide range of diverse answers based on many different assessment tools and approaches[30,43–46] have been proffered, depending on the definitions and dimensions used in the assessment. The need to address the issue of the optimal level of energy security provides further motivation for investigating definitions and dimensions of energy security.

Setting a goal of improved energy security requires a clear understanding of the concept of energy security itself. However, as concluded in many studies, the concept is not defined clearly,[5,6] or is defined narrowly and disparately[34,47,48] with no common consensus.[49,50] The definitions are context dependent and polysemic in nature[2,9,26,49] and the topic is approached with different assumptions[31] and from different viewpoints. Consequently, researchers have described the term as abstract, elusive, vague, inherently difficult, and blurred.[5,26,50–52]

Chronological Analysis of Energy Security Definitions

As mentioned earlier, the concept of energy security is as old as fire. Early humans had to secure a source of fire (e.g., wood) for heating, cooking, and protection,[15] which met human needs at the time. As human civilization developed and new societal structures, fuels and modes of transport were adopted, energy security became increasingly complex. Although the need for energy security has been ever-present, documented definitions of energy security are relatively new.[16]

Study of the evolution of a definition can provide insights into key aspects of the concept; therefore, a trend analysis of documented definitions of energy security is presented. This analysis considers only direct definitions of the concept; literature related to energy security but not explicitly defining the term is not considered. Moreover, definitions that neglect an essential part of the concept are also excluded. For example, the definition 'security of supply'[49,53–58] is an obviously misleading definition because security of supply is only one part of the concept of energy security, as it excludes dimensions such as the environment, continuity of demand, and efficiency.[51] The analysis traces the development of definitions of energy security from 1970 to 2000 in 10-year intervals and uses 5-year intervals for 21st century definitions. Some definitions are reused by later authors. The definitions and the literature where they are presented is summarized in Table S1 (Appendix S1, Supporting Information).

As stated earlier, the analysis in this work begins in the 1970s, where the first available record of a definition of energy security is by Willrich,[59] shortly after the energy crisis of 1973, and a part of the 'environmental awakening' witnessed in the 1970s and the 1980s. Drawing on research such as,[60–62] Willrich[59] defined energy security as: 'Assurance of sufficient energy supplies to permit the national economy to function in a politically acceptable manner.' Although the focus of this definition is on the economy, politics and supply, many other dimensions were discussed in the article. The same definition was used by Miller et al.[63] but fewer dimensions were discussed in their work. Later, Deese[64] introduced the notion that energy security is a condition, a situation, or a status rather than a policy or an attitude. Deese emphasized the 'nation' as a whole rather than considering individuals and subgroups. Availability of resources is the focus in these two definitions, reflecting prevailing global conditions.

The 1980s saw few attempts to define energy security, an indication of greater international stability. Lovins and Lovins[65] introduced a definition that argued that energy security is to be reconsidered with more dimensions than merely the ability to keep the oil flowing (or energy availability).

In the 1990s, following the Gulf War, energy security was defined by Bohi and Toman[47] by defining its opposite, i.e., the loss of welfare because of process changes (e.g., oil price fluctuations due to conflicts). In this decade, the notions of national security and regional security were emphasized by Neff.[66]

At the beginning of the 21st century, research literature started to provide more precise definitions, and energy research started to see greater involvement of international organizations. The definition by the United Nations Development Program (UNDP)[67] introduced new notions of locality, supply, and import, in addition to availability. A similar approach was taken by the International Energy Agency (IEA) by defining the term using the notion of physical availability of supplies.[68] While the availability of local physical resources is clearly an important dimension of energy security, such availability can result in what has been termed as 'energy curse.'[69] In addition to price, supply reliability was later introduced into the definition.[3]

Two years later, the definition was developed by the inclusion of the state of being free of risks and disruptions,[70,71] which was a notion that had previously been discussed by Neff.[66] The Iraq and Afghanistan wars affected energy perspectives, resulting in a necessity to include freedom from risks in the definition. The focus on possible risk spurred the UNDP[72] to update their definition by adding a further dimension to energy security—the environment.

The trend of adding more dimensions to the definition of energy security continued in 2005 with the inclusion of infrastructure,[73] national power,[74] and sustainability.[75]

The period 2006–2010 saw considerable development in study of energy security, and 21 different definitions can be found in the literature. The approach of adding more dimensions to the definition and attempting to define the term by the sum of its components continued. Hughes[76] refers to the role of governments and polices, Bruusgaard[77] emphasizes the notion of the state, and Yergin[17] focuses on two dimensions (availability and cost) to define energy security. Inclusion of the timeframe dimension was seen in 2006.[78] Through the whole period, definitions introduced a variety of new and extended notions ranging from the availability dimension,[79] the environment dimension,[80] the cost dimension,[81] the efficiency dimension,[82] the sustainable considerations,[10] and the military dimension[83] to the notion of risks and threats to the economy.[35] A new element was introduced to the definition when the new term 'sustainability' was added.[84]

Many definitions tried to simplify the issue of energy security by including important parameters in the definition. However, some dimensions are still missing (e.g., culture, environment, and technology), making the definitions deficient. A further change occurred with the inclusion of electricity in the definition,[85] whereas previously oil had been considered the main source of energy.

The years since 2010 have witnessed different approaches to formulating a definition of energy security. In the beginning of this period, researchers tried to add as many different dimensions as possible,[33,86–92] which was a continuation of the previous trend. A feature of this approach is that the definition of energy security became longer and longer, as researchers found more dimensions worthy of consideration. An alternative approach to formulating the definition was seen in 2012, when researchers aimed to resolve the question of 'What is included in energy security?' by simplifying the definition so that it can be used for different sectors with different perspectives. The first innovation was by Johansson and Nakićenović,[93] who provided a definition that can be used with any energy system, whether oil, gas, or electricity, etc. The notion of risk and threat was partially presented. However, a weakness with their definition was that it was limited to the energy provision point of view (services) and failed to account for the producers.

From the research point of view, simplification of the definition seems attractive as long as the definition includes all sides. In 2013, Čehulić et al.[94] attempted to formulate a very simple definition by defining energy security as: 'The freedom from disruption of energy supplies for whatever reason.' This definition has the advantage that it can be used for any perspective in any dimension but the drawback that it focuses only on the supply side. Another innovative definition was provided by Jewell et al.[95,96] Their definition: 'Low vulnerability of vital energy systems,' is conceived in very wide, general and vague terms, and thus needs further explanation. According to their approach, the meanings of vulnerabilities, vital and the systems in consideration need to be defined, i.e., the terms need reformulation to give better understanding. A further attempt in providing a simple definition was undertaken by Kucharski and Unesaki.[48] They defined energy security as 'Assessing various types of risk in the energy system.' The drawback of this definition is the notion of energy security as an action. While assessing the risks can be a part of having a higher level of energy security but it does not cover all aspects. Making new laws, for example, is a step subsequent to evaluation and is a part of the energy security concept. However, the use of the term 'risks' is important for the definition, as will be discussed later.

Noticeably, the number of researchers providing a definition for energy security increased vastly in this period. The 29 different definitions within 5 years show the disagreement in the scientific community regarding how to deal with the issue. As can be seen in Figure 1, the number of researchers providing definitions of energy security has increased over time. The second trend is the way in which researchers have approached the concept; at first, the definitions are simple and general but sufficient for their time. Then, researchers started to include more terms within the definition to show that different parameters are involved. The last change was simplification but with provision of more comprehensive terms so that subparameters were removed but references to them were included in the definition.

As mentioned earlier, other researchers have tried to discuss the concept but have confused it with other terms (e.g., security of supply is the focus of most researchers[97]) or have not provided a clear definition. There is an obvious difference between energy security and security of supply,[18] which fails to include important dimensions of energy security. For example, Hoogeveen and Perlot[54] state: 'Security of supply is a general term to indicate the access to and availability of energy at all times.' The same limitation can be found in other literature.[5,49,53–58,98–104] Only recently, scholars such as Erdal et al.[105] have started to differentiate between energy security and security of energy supply, providing different definitions for each concept.

Adopted Definition

As Aristotle reputedly said, 'he who controls the definition, controls the debate.'[32] Thus, a suitably generic term to cover all aspects of the concept is needed to overcome the complexity of the term.[10] The first step in formulation of such a definition is to include the three parts of the energy system, supply, demand, and transfer, as UNDP et al.[72] suggest that energy security should not only be focused on security of supply. Furthermore, if energy security is to be defined comprehensively, the concept of sustainability has to be taken into consideration.[106] Also, the concept of threat, risk, and vulnerability, i.e., the degree to which the system is unable to cope with events,[107] should be included.

Energy security has two words 'energy' and 'security.' According to the Oxford dictionary, energy is the strength or the power that can result in work. From another perspective, energy can have different forms but never disappears nor is created from nothing; it changes from one form to another (first

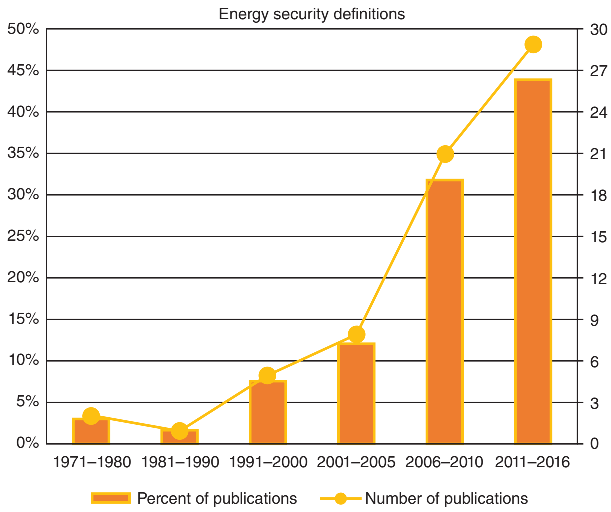

FIGURE 1 | Scientific documents defining energy security, occurrence percentage and numbers in time spans.

law of thermodynamics). Energy is thus: kinetic in moving objects, heat in small particle movement, electrical in electricity grid, chemical in molecular bonds (e.g., oil or gas), electromagnetic (e.g., solar irradiation), and so forth.

On the other side of the term, 'security' means: 'the state of being free from danger or threat,'[108] 'freedom from harmful threats'[71] or in the words of Arnold Wolfers, 'the absence of threats to the adopted values.'[109]

Therefore, in this work, energy security is defined as the *feature* (*measure*, *situation*, or *a status*) *in which a related system functions optimally and sustainably in all its dimensions, freely from any threats*. By this definition, all perspectives are taken into consideration, any dimension can be included, and all risks can be accounted for.

DIMENSIONS AND PARAMETERS OF ENERGY SECURITY

Following the definition of energy security in the previous section, the paper next considers dimensions and parameters of energy security and their relationships. Previous work has listed a large collection of dimensions and parameters that are important for energy security (Table S1, Appendix S1, Supporting Information), and the literature has diverse approaches to determine factors to be considered when dealing with energy security. Some researchers use dimensions[32] and some use aspects.[93]

The use of many parameters has been criticized, because the term should not be too specific and more indicators do not guarantee a better assessment.[30] However, any dimension or parameter that has a relationship with energy security should be addressed because, as Yergin[17] states, 'energy security discussion should be expanded to include more dimensions,' because energy security challenges are heterogeneous.[32] The degree to which each parameter is linked to energy security and its significance differs. Thus, there is a lot of index analysis in literature[51] in which researchers try to give a numerical value to energy security parameters in order to make a general evaluation[51] of the security of a system against certain threats.

The methods to measure energy security differ a lot in literature. As summarized by Ang et al.,[1] there are many different ways to measure energy security based on the interest of the authors and the dimensions they include. First, authors attempt to study a specific location or period of time. Then, they choose their focus area of which dimensions are important to them. After that, indexes are formed to cover only the wanted dimensions from energy security. The methods to construct numerical indexes vary. First, each dimensions or parameter is given a value. Then, these values are normalized to one another. Normalization can take place by a min-max, distance to a reference point or standardization. After the studied dimensions and parameters have the same meaning of their values, the impact of each value in the course of energy security evaluation is given a weight. Weighting can be done in several ways, for example, equal weights, principle component analysis (PCA), or analytic hierarchy process (AHP). The last step in these methods is to put all the values for dimensions and their weights in aggregation. Aggregation of all the informative data inherited in each dimensions provides a numerical energy security index.

However, it is out of the scope of our article to give numerical values of how a parameter can be measured. Here, the aim is to address all possible factors, even though some of them might be interconnected, but as none of the parameters is identical, all parameters can provide information and insights. How to measure the exact parameter and how important it is differ based on the perspective, the interest, and the desired result.

To analyze energy security dimensions and parameters, our approach has three main parts: analyzing the different dimensions and parameters one by one, illuminating the relationship between the parameter and energy security, addressing the threats to each dimension, and discussing indexes that can be used to measure energy security parameters.

In most of the dimensions, the energy system is described by three parts: The energy source (production), the energy services (consumption), and the transfer from the production to consumption.[48] Furthermore, the first-order relationship and impacts between energy security and different parameters is to be taken into account.[25]

Availability

This dimension is a critical dimension for energy security. Availability is always included in the discussion.[50] The importance of energy availability lies in its support of economic and welfare growth; when availability is weakened, it limits economic expansion and lead to changes in technological and consumption patterns.[89] In that sense, availability is discussed in relation to access to services,[6,51] to sufficient supplies,[36] or to the availability of consumers.[110] Therefore, availability has three parameters: *availability of energy resources*, e.g., oil or gas, *availability of means to transform resources into services*, e.g., energy infrastructure or pipelines, and the *availability of energy consumer*, e.g., public use of energy or industrial use.

The principle meaning of availability is existence. Therefore, the three main parameters of the availability dimension should exist. If energy resources do not exists, there is no notion of energy system, so the first parameter is that energy resources have to be available. Nowadays, the current energy system has no problem with energy resources. The global coal reserves are $1{\cdot}10^7$ TWh, the global oil reserves are $2.5{\cdot}10^6$ TWh, and the global natural gas reserves are $2{\cdot}10^6$ TWh.[111] The global energy assessment (GEA) has ranges for the reserves based on different literature and differentiating between conventional and nonconventional resources. The values are for global coal reserves $0.48{\cdot}10^7$–$0.6{\cdot}10^7$ TWh, oil reserves $2.4{\cdot}10^6$–$3.7{\cdot}10^6$ TWh, and gas reserves $0.7{\cdot}10^7$–$2.1{\cdot}10^7$ TWh.[93] Another estimation for the current resources is made by Perez and Perez.[112] The global coal reserves are $7.9{\cdot}10^6$ TWh, the oil reserves are $2.1{\cdot}10^6$ TWh, and the gas reserves are $1.9{\cdot}10^6$ TWh.[111,112] Based on current global energy consumption, oil reserves are enough for more than 55 years,[111] 52 years of current production,[113] or for 23 years if global consumption grows by 5% annually.[114] Also, the world's proven reserves of coal are estimated to last for 122 years of production at current rates,[113] proven reserves of natural gas (conventional and unconventional) are estimated to sustain current production levels for 61 years.[113] In addition to these resources, there exists what is called ambient/renewable energy (e.g., wind power, solar energy, flow-of-the-river, and marine energy), which principally can be used to cover the demand.[82] For example, the theoretical potential of solar energy alone is (89300 TW),[115] that is approximately 7000 times the global energy consumption in 2013 (162 TWh).[116] Therefore, energy exists plenty and sufficiently to cover all global demands as *per se* for the foreseeable future and hence many energy analysts, from the past as (1970s) and the more recent (2000s), agree that there is enough energy to meet global demand.[84,117] Thus, there is no energy security issues in regards to availability of the energy sources on a global level.[67,72] However, the resources (mainly fossil fuels) and the demand are not distributed evenly around globe.[60,67,118] Therefore, existence of energy resources can be a constraint to achieve energy security if the perspective is narrowed down to a specific small populated area (e.g., Shanghai). On the other hand, if renewable energy (solar, wind, biomass, and hydropower) sources are taken into consideration, there is a more balance between the existence of resources and demand. The distribution of these resources is much more even than fossil fuels and thus the demand in different places is covered by nearby renewable resources.

The second parameter of the availability dimension is *the consumers (demand perspective)*. The demand parameter is as legitimate preoccupation as the resource parameter for countries where their revenues are from energy exports.[90,119] Nowadays, the discussion about the demand side is taken place as part of energy security as what is known as 'security of demand.'[17] From energy producers' perspective, energy security denotes a quest for a market for their energy exports which correlates to increased (government) revenues.[10] Today's population is around 7.35 billion and still expected to increase to 11.21 billion in 2100.[120–122] Thus, people will continue to demand energy for various needs. Hence, as long as humans live, there will be available consumers for the available resources. Furthermore, the need for energy in different sectors of an industrialized society is high. Thus as long as the civilization continues, the energy demand will continue. However, the level of demand is a matter of disagreement, but for humans to live comfortably, individual consumption should reach at least about 40 MWh/cap.[123] These numbers seem incredible in contrast to the figure of 1.6 billion people (20% of global population) who do not have access to modern energy services.[124] Therefore, in order to live a sustainable future, all those people should be provided with energy (electricity) to reach the individual consumption demand. That picture confirms the increase in demand predicted by many agencies.[113] This means 'security of demand' is assured. The final question is how to utilize these resources for the growing demand in a sustainable way, the answer is renewable energy as Breyer et al.[123] conclude.

The last parameter of the availability dimension is *access to these energy resources* transferring them to energy services for consumers, which is usually the concern for researchers. Having access to the energy services was a concern through the history.[125] Individuals, societies, and countries paid a huge cost to obtain such access. Full access that results in the provision of needed energy services to consumer is considered to enhance energy security and hence drives the development path of a society.[89] On the other side, less access reduces energy security. The access importance is infrastructure-related. Secure infrastructure and transport routes are essential for energy security[90] because energy infrastructure is one of the most vulnerable elements of modern societies.[80] For such, breakthroughs in developing infrastructure are needed to enhance energy security.[126,127] For example, developing new technology to harvest solar energy or new methods to generate electricity from water, both as sources of renewable energy.

Nevertheless, there are comprehensive risks and threats associated with the availability. Energy existence abundantly in one location with ultimate access can deteriorate energy security resulting of many problems such as the 'Dutch Disease'[128] or 'Resources Curse.'[69,129] The Dutch disease occurs by the overvaluation of the currency of a country usually because of the export of natural resources.[130] This leads to the loss of competitiveness and thus deindustrialization of the economy. As was found by Cavalcanti et al.,[131] abundant availability is not the driver for Dutch disease *per se* but rather its volatility. The other burden is the resources curse. Principally in most of the cases, energy availability tempts those who are in power to use it for their own benefits even if it is against the benefit of their people. The situation follows the political environment of when the resources were found; if a country is stable with determined roles for people in power and legitimate body to check on them, the newly found resources are less probable to be a curse. Otherwise, if there is no questioning to those in power, the resources are highly probable to be a curse.[132,133] In other cases, other nations or governments decide to control the access to an energy resource by overthrowing current controllers or owners, starting a war against energy rich countries (resource war). Resource wars, defined by Ciută[31] as hot conflicts triggered by a struggle to grab valuable resources. Furthermore, disrupted or limited access to the required energy like absence or ruin of infrastructure[134] will result of what is referred as energy poverty.[126] Energy poverty increases social difference and political tension and blocks the way to development.[80] In real life, destruction of production or processing infrastructure comes with the biggest risk.[21] Another threat to the energy system is the depletion of energy sources,[135] which is sometimes exaggerated.[127] If it happens to utilize more of renewable energy rather than fossil fuel, it will happen not because of fossil fuel depletion. As Sheikh Yamani, the former Oil Minister of Saudi Arabia, said 'the Stone Age did not come to an end because of a lack of stones,'[127] but due to economic reasons.[136] Furthermore, poverty can be worsened or alleviated by the energy access level[32]

The numerical indexes that can be used are different, for example, reserve to production ratios,[49,82] reserve per capita,[51] resource estimates,[137] or total energy resources per capita.[36] However, many of these indexes will be of no use in a future energy system that relies on renewables because they were designed for a fossil-based system. Therefore other indexes will make more sense to measure this dimension, for example, final energy consumption per capita.[29] Last, since energy exists excessively on the global level, the question is left for us (humans) to decide how we want to live on our planet; whether to collapse or to succeed.[138]

Diversity

Diversity is also highly pointed out as an important dimension to enhance energy security.[126] Since the beginning of the 20th century, Winston Churchill the First Lord of the British Admiralty made his famous statement that energy security lies in variety and variety only.[125] The concept of diversity is portrayed by the expression: 'Don't put all your eggs in one basket.'[53] In principle, more diverse systems are more secure.[127,139] In that sense, if one part of the energy system malfunctions, other alternatives can replace it.[17] It is unlikely for all parts to fail at the same time.[67] Thus, the impact is spread among the other parts of the system.[48]

As Stirling[140] presents, diversity's main parameters are *diversity of fuels (energy carriers), diversity of sources, diversity of means to make the energy available to end-users* (e.g., technologies and transportation) and *diversity of consumers* (e.g., markets and sectors).

Energy carriers can be in form of matter-based chemical materials (oil, gas, or coal), or in form of nonmatter-based electromagnetic fields (electricity). A system depending only on oil is less secure than a system depending on oil and gas. The same is to be considered for the source and its location. An energy system that relies on one power plant is less secure than a system with power plant and electricity import.

Diversity of sources is the second parameter. This parameter is related to the notion of dependency (to be discussed below). Simply, if the energy system has only one source, it is less secure than the case if there are different sources. For example, many European countries relied on Russia as their source of gas. This situation resulted in a 'crisis' in 2012.[141] Germany and other European countries had less gas than needed to cover their gas demand. Should these countries have had a divers set of sources and suppliers, the situation would have been easier, and energy security would have been preserved.

Diversity of technology is important because it allows for more options. Development of renewables promotes new energy sources utilization[142] and hence enhances energy security.[40] For example, Germany witnessed an enhancement in energy security in January and February 2017, in contrast to France.[143] Because of security failures of French nuclear power plants several short-term shut downs led to power supply shortage in France and imports from neighboring countries had been required to keep the French power system stable during the winter, due to an ill-balanced diversity of technology in France. In contrast, Germany, with a much higher share of renewable energy (wind and solar) and substantial less nuclear energy than the highly nuclear energy-dependent France, balanced the energy system, in addition to utilizing coal and gas plants output.[143] In this sense, a more diverse system that comprises renewables is more secure and decreases the threat of electricity blackout. The same concept applies for transportation, what routes are used (land or water), how many routes are used, and what methods are used (pipelines, LNG terminals, grid, ships, etc.), all play a role in the diversity dimension. For example, diversification of transport routes diminishes motivation for terrorist attacks,[127] since it may not cause a significant level of harm.

The last parameter is *the consumers' profile*. Having one market (one country) is less secure in comparison to having more markets. Also, being able to provide energy services to more diverse users (industry, commercial, residential, military, etc.) is an advantage for the energy system.

However, this concept of diversity to enhance security can be applied only if all other dimensions are neutralized. Diversification alone is insufficient to enhance energy security if costs or compatibility are not to be taken into account.[48] For example, it is more divers to use coal and oil rather than using oil alone, but the environmental and health impacts of this diverse system reduce energy security as it affects other dimensions. Furthermore, renewable energy takes the lead in building a more diverse and more secure energy system.[144] In addition, in many cases the enhancement does not have counter effects on the cost of the new system (renewables are cheaper), environment (renewables are cleaner), health, employment, etc.

To carry on, following the urge of nations to be independent, energy dependency is a term discussed a lot in literature.[31] However, complete energy independence is merely a myth.[29] Total independence is not a guarantee of energy security at all,[21] neither is dependency alone a concern to be triggered.[145] A dilemma has to be solved first, a total independence means less diversity and more threats by accidents, strikes, or newly discovered environmental effects.[66] Furthermore, many parts and devices of the energy system have to be imported.[29] Therefore, there should be an optimal choice between dependency and diversity. On the same tone, dependency on one country or region is usually discussed in literature. The example that is widely reported is the European reliance on Russian natural gas.[146–148] Discussing this example can provide the cut point between diversity and dependency. If a country gets all of its energy from Russian natural gas (total dependency), energy security deteriorates. On the other hand, if a country relies on Russian natural gas among other sources of energy, their energy system is more secure (diverse). However, if this country decides to run all its energy system on nuclear energy built within its borders (total independent), the system will be less diverse and less secure, not to mention the intrinsic technical risk of nuclear. Furthermore, a country relying totally on nuclear energy within its borders has other negative consequences, such as becoming joint targets in wars[149] or targets to seize and control as an energy resource. It could be argued that for economic reasons, blackouts should be avoided at any cost and nuclear would be the best option for a base load power generation. However, an energy system can be run without base load power generation and new plants face very high cost[150] and the cluster risk of nuclear energy is also high; the cost of its failure on economy, environment, and society is much higher, as documented again in Fukushima.

Some of the indexes to measure diversity's impact on energy security are the diversity of energy sources in the total primary energy supply (TPES), electricity generation and the transport sector,[96] Herfindahl Hirschman index (HHI) for energy supply diversification corrected for political risk,[51] energy trade per gross domestic product (GDP), energy import dependency,[29] Shannon-Wiener index (SWI),[30] and share of renewables in the energy system.[82]

Cost

An interesting dimension that is often treated unfairly is the cost dimension. It is usually regarded as affordability of energy services (the price to be paid for energy). In our view, this is only one parameter for the cost dimension; there are other parameters to be addressed. Since there is a high correlation between energy and economy,[151] this study will consider the different parameters of the cost dimension.

The first parameter is the *relation between energy price and energy security*. In terms of end-users and economy, a cheaper energy price is better because it can increase industrial production, enhance the economic growth, and encourage consumption.[126] This seems to enhance energy security but it is not as simple as that. Since energy security relies heavily on large-scale investment,[78] cheaper energy prices puts a burden on future planning. Also, scarce fund for investment has a structural impact on future prices[152] and hence energy security. Cheap energy prices are a long-term problem because they lead to a false sense of instant security,[153] specially if there is no guarantee of such cheap prices for the future. When there is no guarantee for cheap prices in the future, societies and buyers become vulnerable to any price shocks.[126] On contrast, higher energy prices will reduce demand and encourage development of alternative energy resources,[17] but at the same time limiting growth of energy-importing countries.[154] For example, an increase of $10 in the price of a barrel of crude oil is likely to reduce economic growth in the industrialized countries by around 0.5 percentage points.[25,68,72,79]

For producers, cheaper prices mean less revenue and may result in an economic loss. For a country, a nation or a society, such economic losses affect other services. So, does that mean a higher price achieves energy security for them? Up to a certain point, yes, because higher energy prices mean in the short-term higher profits,[84] growth in new supplies,[17] and an increased capital investment[126] that can be used to establish a sustainable energy system[155] and to achieve energy security.[146] However, on the other hand, higher revenue can cause the previously discussed 'Dutch disease.'

In regards to the first parameter (*energy price*), the last point is the nature of the pricing system. Stability of energy prices,[142] price volatility,[82] pricing system,[155] energy poverty,[114] and peak oil[139] are the most discussed issues. Volatility of energy prices and their impact are the main challenges for energy security[4] because a sudden change in energy prices may disrupt the whole economy.[156] As the World Energy Council states, volatility of energy prices has a critical uncertainty of the future economy.[155] For the pricing system, it follows the political discussion to come in a later sections, principally if energy to be subsidized by the government or not. International Monetary Fund estimates that there is 5 trillion USD of direct and indirect public means allocated to subsidize fossil fuels globally.[155,157] Such subsidies affect the choices and the options for energy sources because real costs are not embedded in the price. The nature of the energy price might result in energy poverty, 'the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development.'[158] This lack of choices can be the result of different causes but artificial taxes and subsides can be a major reason. Another simpler definition for energy poverty is a situation where individuals spend more than 10% of their income on energy services.[114,159] Such energy poverty means the consumer is unable to benefit from the available energy, making it useless and thus deteriorate energy security.[134] Last, it will be worth when talking about the nature of the pricing to notice the significance of the debate about peak oil.[160] The discussion is more about the increase of prices due to decrease in production, beyond the inflection point (supply is less than demand).[139] Such situations reduce energy security. As Zittel et al.[160] conclude, the combined peak of all fossil fuels may occur before 2020 and nuclear fuels' contribution is too low to have any significant influence. Thus, the future needs to be seen and planned accordingly. In that sense, renewable energy is the key for a cost-effective future energy system. The continuous reduction in solar energy cost is a pillar for the future if sustainability is to be achieved.[161]

The second parameter discussed in literature is the *cost of energy security in terms of supply disruption*.[4] In other words, how much it costs if there is any disruption in a running system. The higher the cost of disruption and the more frequent it happens, the less secure the system is. Old estimates for the cost of oil disruption in the American economy are 936 $bUSD_{2016}$ (323 $bUSD_{1980}$) for each 10 million barrels per day for 1 year.[162] Where recent estimates show the expected cost of oil disruption in some scenarios to be between 29.5 and 31.6 b€/a for EU25.[163] Another study estimated Iraqi losses as 7 mUSD a day as a result of pipeline attacks in 2003.[77]

The third parameter is *how much it costs to make an energy system more secure*. Energy security comes at a cost and it is not a question of achieving it at any cost.[18] Since, this parameter is rarely addressed in literature, it is the most difficult to formulize its relationship with energy security. With its well connection to all other dimensions, it is a balance between what is paid and what the benefit is. An example of this parameter is the diversification cost; if an energy system runs only with nuclear energy and then it is proposed to be run on nuclear and solar energy, there should be a balance between the cost and the value of energy security to be attained. Many points are involved: the infrastructure cost for the whole system, the cost of environmental impact, the cost that will be paid for healthcare, the cost of military deployment to protect the sources, the cost of educating people about the action or the cost the society will pay in terms of welfare. Therefore, if the diversification step pays for all of these costs and others, it will increase energy security, otherwise, it will not. An obvious example is the estimate that the United States spends about 50 bUSD a year on security in the Middle East, without counting the costs of special operations like the war in Iraq, which costs more than 100 bUSD a year,[164] which in comparison to Department of Defense Homeland Security expenditures is very huge.[164] In addition, the estimated cost of U.S. force projection in the Persian Gulf for 1976–2007 is found by Stern[165] to be 6800 $bUSD_{2008}$. The question that needs to be answered is: Is this spending justified to enhance energy security?

In that aspect, many researchers seek to find low-cost solutions that enhance energy security far from military deployment but by renewable energy.[136] As a cheap option in the long run, renewables can make the energy system more secure.[166] It starts with the structure of the cost and then the benefits. Mostly, renewables require capital expenditures with less operational expenditures. Thus, an energy system with only an upfront payment and almost zero running costs is considered more secure. In addition, renewables are environment friendly sources, thus reduce the carbon emission costs, making them a more cost-effective option.

From the different parameters, the threats on the cost dimension are diverse. Price volatility and investment risks are threats to energy security[31] because rapid changes in energy prices can disrupt the economy[156] and destabilize financial structures.[66] If prices change rapidly, the risk is the inability to calculate failure probabilities.[65] Another threat is the impact of energy poverty, such situations can rise internal political unrest,[82] for example, Haiti and Cameron.[167]

Last, the exact cost for energy security should be addressed with full consideration of all dimensions not only the price of energy disruption. As Jun et al.[4] tried to provide an index to measure the cost of energy security, they had to limit themselves to a very narrow definition of energy security and they confessed that many other costs are not taken into their consideration. Other indexes measuring the cost are the fixed capital stock renewal factor or GDP per each percent of energy price change,[91] the price's volatility,[51] market costs of energy in €/MWh,[8] economic costs of carbon price,[82] or value of the energy not provided, such as value of lost load (VoLL).[85]

Technology and Efficiency

Since technology is required for utilizing energy,[142] energy security has a strong relationship to the *technology advancement*, directly and indirectly. In that sense, new technological solutions for production, transportation, conversion, storage, and distribution affect energy security.[126] Thus, new technologies provide new energy sources and hence increasing energy security. For example, introduction of new electrolysis technologies gave the energy system a new alternative energy carrier (hydrogen), apart from fossil fuel. New advancement in renewables results in more access to energy, though it is doubted by some researchers[156] but strongly emphasized by others[161] to be a key for a 'more secure energy future.'[168] Apart from the direct impact of new technologies on energy security, indirect effects are huge. For example, advancement in surveillance technology provides early warnings of threats to the critical energy infrastructure, which diminishes the need for large troop deployment.[77]

The second parameter for this dimension is to *enhance the efficiency of the energy system.*[119] Energy efficiency plays a significant role toward achieving energy security.[155] The goal for R&D is to increase efficiency. It was known long time ago that increasing efficiency by technological development does not only make the energy system more secure[40,61,114,169] but also provides a double-win for the climate traits.[154] Efficiency is maximizing the output units per one unit of input[119] by improving the performance of energy equipment or altering consumer behavior.[114] Consumer efficiency is the ratio of energy service to the energy required to deliver that service.[85] When increasing this ratio, increased efficiency will increase availability of energy[85] for other uses. Although efficiency should be considered in energy security,[170] it should not be separated from other dimensions. Efficient systems will affect the cost dimension, because increasing efficiency requires investment that needs to be justified in regards to other costs.

However, the largest gain in energy efficiency is the shift to renewables and energy sector integration on basis of electricity; it was proposed very early by Lovins[62] as a soft path instead of increasing reliance on dirty fossil fuel. In conventional thermal power plants, about two third of primary energy input is lost.[113] This loss can be mitigated by using modern renewable electricity technologies, such as solar photovoltaic, wind energy, and hydropower. The transition from burning fuels for space heating toward (renewable) electricity powered heat pumps increases the energy efficiency by a factor of 3–4. The same gain in efficiency is achieved for the transition from low efficient internal combustion engine to battery electric vehicles. Furthermore, the huge loss of low efficient nuclear and coal power plants will be eradicated by high efficient solar and wind systems. This means gradual efficiency improvements of current appliances do not fix the fundamental problem of an energy system that is still based on burning fuels, which is the main reason for its poor performance in efficiency. Thus, a shift to high efficient solar and wind systems will eradicated the huge loss of low efficient nuclear and coal power plants and result in a dramatic increase in the efficiency of the energy system.

The third parameter is *energy intensity*. Energy intensity is the amount of energy required to produce one unit of GDP.[67] It represents how much energy is consumed to produce added value.[84] Energy intensity can be used to measure the efficiency of the system.[171] Thus, to improve energy security, energy intensity should be reduced (reducing the dependence of the economy on energy).[67] However, the historical development has shown that developing countries first have to increase their energy intensity while building a modern infrastructure and on a more developed level less energy intensive investments are needed for further development.[93]

The last parameter is *energy conservation*. Energy conservation is an inclusive term to describe the actions that result in energy demand reduction[134] by users foregoing some of the services derived from energy use.[85] Energy conservation has a substantial impact on energy security but not automatically an enhancement,[134] because it provides a temporary demand reduction without a permanent behavior change.[85]

However, technology advancement does not always lead to a more secure system. For example, cultural barriers to utilize new technologies can make them useless.[172] In addition, nuclear energy and nuclear proliferation brought a huge risk to the system as its negative impacts on the society and on the environment concern many.[127] Also, the development of nuclear weapons with the mass destruction capabilities carries a huge threat to the energy security.[77] Furthermore, because of the rebound effect, enhancement of energy efficiency does not always improve energy security. The rebound effect is the loss in expected efficiency benefits due to behavioral tendency to use more energy services that are made cheaper (backfire).[173] It is generally expressed as a ratio of the loss compared to the expected benefit.[174] However, a recent review study by Gillingham et al.[175] concluded that a lot of support for the backfire hypothesis is not found due to the limited understanding of the macroeconomic rebound effect.

Although quantifying technological improvement and efficiency improvements is a difficult task,[126] some researchers tried to quantify this dimension with metric indexes, for example, expenditure on research and development,[44] share of equipment with expired service life[91] or electricity distribution losses,[44] and more commonly energy intensity.[105,171]

Location

This dimension deals with the spatial features of the energy system and its relation to energy security. Studies about energy security differ from local to global, from urban to rural, and from national to international, based on the different needs of each study.[33] Haghighi[21] argues that energy security is not only about internal national but also about the regional security. Policymakers, on contrast, are concerned only with national energy security.[96] Therefore, many parameters are to be involved.

The first parameter is about the *energy system boundaries*. When analyzing any energy system, the location, the size, and the boundaries should be determined. Two main points are needed to be identified; first, control area, i.e., the jurisdiction within which the energy system is to be studied, second, size and area of where the system has an impact.[82]

The second parameter is the *location of energy source*. As discussed earlier, the existence of energy resources in a specific location can result in deterioration of energy security. In addition, the location of the resources affects its accessibility, e.g., difference between oil resources in Saudi Arabia and Venezuela, such different accessibilities cause more cost to get the energy from specific resources.

The third parameter is the *density factor*. The density factor can affect energy security positively or negatively. Although, dense systems have higher energy efficiency, better environmental performance, and better social effects,[176] energy resources in a small area, e.g., oil fields or oil countries are military targets, as seen in World War II (WWII).[125] Such situations reduce the energy security because it requires more protection for the transportation routes as was seen in the WW II when United States blocked oil from going to Japan.[125,162] This example supports the view presented by Müller-Kraenner[80] in which he argues that in a decentralized system there are less pipelines and water paths to be guarded by military.

The two perspectives shape the debate between centralized–decentralized systems. Another advantage for a decentralized system is the impact the threats cause on the whole system. Centralized systems are enemy targets and thus reduce energy security.[162] They are much vulnerable than decentralized systems,[65] especially if technical failure probabilities and social acceptance are taken into consideration. For example, in a centralized system, bombing of a single substation enabled a military coup in Chile.[125] On contrast, in a decentralized electricity generating system, an earthquake in one region will not affect the whole system as much as centralized facility affected by an earthquake.[162] For this, Franki and Višković[8] argue that decentralized systems that use renewable energy enhance energy security, because it combines the advantages of a centralized system (higher energy efficiency, better environmental performance, and better social effects[176]) with the security advantages of the decentralized system. Therefore, developing decentralized renewable energy systems is the future to enhance energy security.

The *land use* is the next parameter. The concept of deforestation is usually discussed in literature. Forest that is cut to generate energy with all the negative impacts of carbon dioxide (CO_2) emissions, reduction of natural habitat, and causing visual pollution shows obvious negative impacts of energy use.[60] Furthermore, usually the landscape is altered[135] and the land is left in an unromantic moon landscape as in lignite coal mines.[80] The food-energy nexus is a clear example of how the conflicts between the land use for energy and for food production can take place. Moreover, another point is the energy waste, such as nuclear waste.[177,178] Currently, the waste is just stored somewhere. The storage location (which is usually designed for an extremely long term) can cause a lot of conflicts especially if it is close to human activities, because of its health, environmental, and social impacts. Furthermore, as will be seen in the culture dimension, awareness about energy technologies increased, thus a new concept evolved 'Not In My Back Yard' reducing the available lands for energy production. Many people refuse to have the energy generation or processing close to them, but do not show such concern for locations far from them. The concept 'NIMBY' (Not In My Back Yard) differs between people depending on what informative streams they are encountered with, but also whether they receive direct or indirect benefits. Thus, many people resist having nuclear or coal-fired power plants near them because of the harmful impact, but others resist renewable because of the false information that they were given about certain technologies or because of ill-balanced benefit sharing.

Another parameter is *globalization*. Since the future of energy system is seen with mutual benefiting and fair competition in a globalized world,[70] regional and international interconnection will enhance energy security.[155] The dilemma with such a globalized system is the definition of control area (defined by national borders with a state). The states are challenged by global processes from above, and by the forces of regionalism and localism from below.[97] However, a recent research indicates that a decentralized renewable energy system is possible without global trading of energy thus reducing risks.[136,179]

Furthermore, the *human settlement and population distribution* play a role in shaping the energy security. As humans are the end-users of the energy, historically, they used to settle close to energy sources. However, nowadays the situation is the opposite. The energy producers should have access to more consumers to assure continuous demand. More population in one region means more market and more demand. Energy resources found in Alaska are transported to where the demand is rather than people moving to Alaska. However, such global interconnection with long distances between the energy source and end-users increases risks of energy security.[65]

On the same tone, the *location's geography* affects the energy security. For example, geography of Strait of Hormuz has more importance for the oil pathways out from the gulf region (20% of the global crude oil trade)[90] or strait of Malacca where 80% of Japan and Korean oil passes[17] and 30% of shipped oil around the world.[90] The threat of disruption is higher in smaller areas. Thus, high traffic density and less diverse rout options with more military deployment reduce energy security. On the other side, during WW II, America managed to find plenty of different routes to supply Europe with energy through the wideness of the Atlantic Ocean. Further and apart from the military consideration, dense energy industry is a threat to energy security, 97% of mankind industrial production come from fossil fuel.[60] Larger power stations tend to have complex failure modes, more difficult repairs and higher unit costs of spare parts.[65]

The last parameter is *industrial intensity*. Energy intensive industries are vulnerable to energy disruption. Therefore, redistributing energy intensive industries within a country or to other countries reduce the risk to the economy and increase energy security.[66]

Many indexes can be used to evaluate the location's effect on the energy security such as nuclear waste per m^2, environmental footprint of energy facilities or the distance for energy delivery from suppliers to consumers.[102]

Timeframe

This dimension is related to how the energy security is seen. Does energy security need to be considered on a long run (+500 years) or a short term (one year or less) to provide relevant information?[82] Moreover, what is the optimal time span for energy security to be studied? Short-term considerations attract attention of private stakeholders[82] and policymakers.[96] For long term, key concerns are for policy analysts and informed policymakers.[82]

On contrast, energy-related decisions made today have long-term implications for how energy is produced, stored, and used.[126] Because, the future energy system is likely to differ than today's energy system,[151] in the long run, energy security depends on the risk management of the present.[180] The relationship between the timeframe and the energy has three parameters as summarized by Sovacool[32]: *to look forward or backward, time an event takes to cause an impact and how long an impact lasts.*

The first parameter is to determine where to see the current energy system in *relation to the timeline*. It has the two notions of forward and backward. To look to the past and analyze how the current system was achieved. On the other side, to look to the future and predict how the future energy system will look like to be secure.

The second parameter, *length of the event,* is related to events that occur in the system, how long an event needs to last in order to build up and be able to cause harm on the system.[97] Stress or sudden events affect the energy system differently. Long-term rising prices for energy import affect the economy differently than a sudden price hike.[25]

The last parameter is the *length of a struggle* in the energy system due to a specific event. For example, the formation of IEA was due to the 1973 Arab oil embargo (event), but (the impact) is still seen as the continuous operating of IEA.

Wrong analysis of the system due to wrong timeframe use is the biggest threat. The enormity and longevity of the energy investments require consumers to participate actively[126] to avoid deterioration of energy security. Dealing with the threats has short-term component and a long-term component. For the short term, emergency measures such as coordination of energy stocks are needed. For the long run, policies to diversify the energy system, to enhance flexibility, and to increase energy efficiency are needed.[68]

An index to determine the optimal time span would be life expectancy index,[181,182] technology cycle,[170] or timely bilateral agreements.

Resilience

Resilience had a lot of discussion in recent years.[15,183] Resilience means the ability to withstand diverse disruptions[93] without experiencing a change in the energy security baseline,[33] an adaptive capacity,[36,48] or the capacity to tolerate disturbance and continue delivering services[184] with the same function, structure, identity, and feedbacks.[89] Yergin[17] refers to resilience as security margin because in general a more resilient energy system results in enhancing energy security[21,96] as long as other dimensions are not worsened, e.g., significant unjustified cost.[68] Thus, the whole point of resilience dimension in these definitions is the ability to function after disturbance. For this, Johansson and Nakićenović[93] link resilience with diversity dimension, that, if one part fails, the system switches to other alternatives. A resilient system can switch between different energy suppliers, different energy transition pathways and energy carriers, and different consumers.[102]

For the energy supply, there should be emergency stockpiles.[48] These stocks, e.g., stored energy in batteries or hydro reservoirs or oil tanks, are stored until they are needed. Creating such spare capacity enhances energy security.[84,126] For the energy transfer facilities, the system needs to absorb the disturbance and still functions, for example, the ability to switch immediately to another fuel, other equipment, or infrastructure.[68] For the consumers' side, energy producers should be able to sell their energy to other customers if a disturbance takes place. Also, they need to have spare capacity in order to increase production when energy is more demanded.[127]

The risks resilience lies in two parts, being rigid and being static. Both follow the concept of passive resilience and active resilience.[65] Passive resilient systems can bounce without breaking, trying to get back to their stable situation till the disturbance is gone. Active resilient system can learn, adapt, and profit from the change or the stress by using the events of failure.[65]

Several indexes can be used to evaluate resilience, for example, emergency stockpiles or capacity margins,[36] spare production backup supplies and storage capacity and national emergency plans,[17] resilience capacity index (RCI),[183] or ratio of total primary energy supply to GDP.[185]

Environment

Environment is what surrounds us. When energy systems are to be considered, the environment is regarded as an important dimension. Therefore, an environmental view of energy security needs to be considered internationally.[142] For that, there are many parameters to be included.

The first parameter consists of *energy resources, rate of exploitation, and location shape after exploitation*. The issue of earth resources is an important determination of the environment.[29] Resources should not be depleted faster than the natural ability of regeneration[135]; else, energy security is reduced. In history, humans plundered the plant resources without considering the negative consequences.[135] Even nowadays, humans use 140% of the resource and absorption capacity of planet earth with a tendency to increase.[186–188] This massive impact of human activities on planetary systems initiated even a new age, called Anthropocene.[189–191] Rebalance of human activities to the limits of planet Earth had been already identified by Meadows et al.[60] but it took long time to find first indications that it could be done without shrinking population or economic activities, but on basis of 100% sustainable and renewable energy systems.[123] Such fast exploitation of the resources makes the land useless for food production with projection to be severely compromised by climate change.[154] Last, energy resources in many cases are hazardous material[32] with negative impacts on the environment and the people using it.

The second parameter is the *extraction methods*. The extraction methods themselves should not cause harm to the environment. In addition, the methods for the energy transfer should be secure environmentally. An obvious example is the oil spills in different oceans, killing the sea environment (flora and fauna). Energy security is deteriorated by such events. The method of extraction for wind energy depends mostly on wind turbines that can affect avian mortality.[32] In addition, CSP (concentrated solar power) has the threat of high temperature spots that might cause death to flying animals. However, the death of birds per generated energy unit is substantially higher for coal-fired power plants due to the very harmful heavy metal emissions.[192] Furthermore, extraction of nuclear energy generates a lot of radioactive waste. The disposal of such waste is an unavoidable dilemma when it comes to energy security.[193] And recently, the fracking technology of shale stones to extract shale gas is very dangerous for the environment because of the used chemicals and the need to destroy the earth layers all the way down to the shale.[194]

The third parameter is the *outcome of the energy usage*. It is the most noticeable impacts of humans using energy systems. The CO_2 and greenhouse gas emissions, global warming,[60] climate change,[106,195] heavy-metal emissions, water contamination,[87] acidic rain,[106] air pollution,[196] and indoor suffocation[197] are among the environmental challenges resulting from energy systems. One example of energy use impacts on the environment is nitrous oxide production. Nitrous oxide diffuses up to the stratosphere, where its photochemical products attack the ozone layer allowing harmful ultra violet (UV) irradiation to penetrate to the earth.[65] For these considerations, the energy system is more secure with less harmful environmental impacts. The developed concept of ecological footprint measures the impact of humans' consumption including energy and food.[186,198,199] It is simply, the amount of nature that humans occupy in order to live with modern consumption of energy.[200]

The fourth parameter is the *effect from climate conditions and climate change on the energy security*. Some natural events happen regardless the energy system, such as earthquakes and volcanoes whereas some disasters occur because of humans activities as a result of climate change.[195] These events affect energy systems profoundly.[126] The effect can be positive and can be negative. For example, the environmental conditions of climate change can enhance energy security by reducing heating demand, providing new trade sea-routes, revealing new energy exploration locations for oil and gas, generating the possibility for more biomass converted from increased CO_2 levels and utilizing more of wind energy.[124] As Johansson and Nakićenović[93] describe, energy security can be enhanced by the new opened marine transportation routes as a result of a retreat of Arctic Ocean. However, on the other side, the negative impacts are seen to overthrow the positive ones by orders of magnitude, that is, environmental conditions can deteriorate to a point on which societies cannot function anymore and nations reach the point of collapse,[114] even humans cannot live outside anymore.[201] Such situation impinges energy security and many examples can be drawn up. If the entire inland ice of Greenland melts due to climate change, the worldwide sea level will increase by 7 m.[80] Taking in mind that most of the worldwide assets are located on shorelines, the severity of such event is clear. Even if such an event will not have an impact on the society and the assets, rising sea levels will require redesigning and reconstruction of the energy systems,[126] which will cause incredible high cost. The example of societies becoming close to the collapse point is what was seen in Hurricanes Katrina and Rita (August and September 2005) which affected the electricity and gas energy systems.[17,202] Therefore, tougher and unstable climate conditions reduce energy security. Thus, weather patterns are a major energy security concern for the global community.[155] The German Advisory Council on Global Change reported the impacts of the climate change on: freshwater resources, food production, storm and flood disasters, and climate migration.[203] All these four have direct and indirect effects on energy security of the energy system. Scarcity of freshwater will lead to conflicts and water wars destroying energy systems. Deterioration of food production will result in conflicts that are initially limited to local levels then worsened to destabilize neighbor countries through refugee flows, arms trafficking, collapse of social systems, and violent conflicts. Storms and floods resulting from climate change destroy energy routs and transfer infrastructure, generation, and extraction facilities; thus, the energy security of the system is deteriorated by climate change. The climate migration is predicted to be a huge issue, because climate change induced refugees fleeing tough conditions will head toward safer places, which will result in more demand and pressure on energy resources.

The fifth parameter is the *energy-water nexus* (interdependence between water and energy).[204,205] An important part of the environmental dimension for energy security is water. An increase in energy demand will lead to an increase in water demand and vice versa.[111] Water is required for energy generation, heating, and extraction of natural resources. Also, water needs energy for its extraction and treatment. Therefore, there should be a balance between the consumed energy to produce drinkable water and the water needed for energy generation.[206] A secure energy system is the one that achieves that balance. Thus, many researchers try to find that balance. For example, Caldera et al.[207] propose renewable electricity based seawater desalination to achieve the balance.

The threats to this dimension are diverse including, but not limited to, the impacts of climate change such as storm surges.[126] The impact of climate change and the failure of good adaptation policies are considered in 2016 as the most threatening risks for years to come.[208] Another threat is the ignorance of the relationship between the environment and the energy system; some researchers argue that there should not be an environment dimension for energy security.[96] In that view, climate and energy security are district concerns and should be addressed by different communities of policymakers because of the lack of proof that climate change would necessarily reduce energy security.[124] Our stance is different, environmental concerns should be a dimension in energy security, because there are risks and threats related to the environment involved in the energy system. One obvious argument to support our point is the radioactive nuclear waste. Many researchers found that there are a well-connected relationship and sever impacts from nuclear materials (as part of the energy system) on the environment.[209–211] Also, radioactive waste must be managed properly so as not to cause harm to people or permanent damage to the environment.[212] But, until the moment, there is no any satisfactory solution to nuclear waste problem.[32,213] The energy system strongly affects the environment and thus the environmental dimension is to be included in the energy security discussion. As Jun et al.[4] put it nicely 'No form of energy production or use is without environmental impact.'

Last, many indexes are used to evaluate the environmental dimension. For example, generation of energy related radioactive waste, lifecycle carbon emissions, or water withdrawals per kWh[36] water stress,[111] CO_2 emissions per capita,[30] and carbon intensity, i.e., CO_2 production per kWh consumed[171,214] are all possible indicators. One indicator that was addressed before is the ecological footprint.[215–217]

Health

From the surrounding (environment) to the main concern (humans), energy security affects and is affected by the health of people; healthy life is a universal human desire.[60] In this sense, there are two main parameters for the health dimension with many points within each parameter.

The first parameter is the *impact of healthy individuals and society on the energy system.* Starting from people who are involved in energy production, they must be in a good health to do their tasks. Healthier workers have a higher productivity[218,219] and thus the energy system will function more efficiently and hence enhance energy security. The second point is the health of people involved in the transfer section. All energy sector employees are to be concerned. Less sick absence means less expenditure on healthcare. In addition, productivity of energy sector workers increases with healthier workers. The last point in this parameter is the impact of healthier consumers. Healthier consumers use energy more effectively and thus enhance energy security. A healthier society reduces the healthcare expenditure and hence enhances the national economy, which in return, will make the energy system more secure. They can spend more on sustainable options and thus more efficient systems. Alternatively, they spend the money on developing new technologies that enhance energy security.

The second parameter is the *impact of the energy system on the health of individuals and societies.* If the energy system affects national and international health negatively, its security is deteriorated, and vice versa. In this parameter, there are three categories of people affected by the energy system. People involved in the energy industry in any of its stages. End-users and consumers of energy services. Last, the national and international society that is affected by the energy system even if they do not use it.

In general, effects on workers in energy industries are the second biggest health impact globally.[93] If the energy exploitation affects workers' health, it reduces energy security. Many examples are there, for instance, though negative effect of nuclear energy is aimed to be avoided,[184] many workers suffer long-term diseases. Furthermore, German Federal Constitutional Court decision about the accelerated nuclear power phase out in Germany is quite important for future nuclear investments. The court emphasized in its decision that phasing out of nuclear plants could be even accelerated for the common welfare, to protect life and health of the population, to protect the environment and future generations.[220] Workers in the coal extraction mines suffer from different diseases. Coal exploitation releases tons of toxic materials that contaminate water and impair health.[221] In addition, 70% of rail traffic in the United States is due to coal transportation, and rail transport is associated with accidents and deaths.[221] Also, most of the energy carriers are hazardous materials,[65] threatening energy sector workers.

The second group is the consumers. Many use fossil fuel and dirty energy for their daily life uses. The word dirty energy is derived from the outcome of the energy use that is usually ashes and emission (in addition to heat and light). Emissions result in cases of suffocation and long-term cancer.[222] Such direct impacts on the consumers deteriorate energy security.

The last group is the national and international society. More than 5% of all health issues around the world are due to the current energy system, in addition to 5 million deaths per year.[93] Even if these individuals are not involved in the energy system, they are affected. Many obvious examples exist; nuclear waste reduces societies' health.[66] Chernobyl accident in Ukraine or Fukushima accident in Japan affected millions of people. Heavy metal emissions from a coal-based energy systems result in cancer and other diseases.[222] Since energy systems affect everyone in the society: doctors, teachers, soldiers, and so on, the whole society loses its functionality if these people are not able to carry on their duties due to negative impacts from the energy system.

The threat to this dimension is the lack of recognition and less awareness of the connection between health and energy security and thus no actions are taken to solve the problems. The reasons for this lack of awareness is subsidies as summarized by Coady et al.[157] For example, additional 30–170 million people will suffer from malnutrition or undernutrition by 2080[203] if the problem of climate change is not solved. On the other hand, if the problem is solved, annual benefits (less expenditure on healthcare systems) range from 5.7 to 210 mUSD.[223] The solution is promoted by many researchers to be renewable energy.[123]

Examples for indicators in this dimension are: health spending per capita with the United Nations Human Development Index,[182] the infant mortality rate (IMR),[224] or emission per capita.[221,223]

Culture

Culture is an important aspect of energy security.[154] In general, cultures affect how people shape, react, or deal with specific issues. In some literature, it is referred to as social acceptability[225] or public participation.[154] On the other side, events and conditions can change some parts of the culture.[226] In that, energy systems and energy security are not an exceptions.

Since energy system instability has a cultural and social nature,[94] the first parameter is thus *how cultures affect energy security*. Humans' effect is seen in the three stages of energy systems (production, transfer, and consumption). In the production stage, energy poverty will encourage societies to produce energy anyhow to cover their demand even if such energy resources cause a lot of harm on the environment or the health (reducing energy security).[12] Another example of how can culture affect the production stage of the energy system is the Bolshevik revolution in 1917. The revolutionary spirit and culture made the workers to stop the oil production from Baku's oil fields.[125] Nationalization of energy production facilities has affected and will affect the energy system and its security.[125]

The way how energy flows is affected by public and private suppliers. If the culture is more materialistic, suppliers tend to concentrate on meeting the energy demand from industrial consumers at the cost of the poor with low demand,[227] this attitude will hinder energy security of the other part of the society, the poorest.

When it comes to the consumption side, liberal individuals are more likely to engage in a responsible consumption behavior to achieve energy security.[228]Social justice promotes secure energy systems that benefit the masses rather than the few elite.[88] Furthermore, from demographic point of view, age and gender play a role in the consumption attitude in regards to energy security.[228] For example, the youngest groups show that energy security is in their top priority in comparison to elderlies.[228] These findings have put more pressure to find solutions for the demographic transition into older societies.[229] Having more young citizens will alter the energy consumption into a sustainable scheme. The solution that many countries opt to is to stabilize child/woman ratios at around 2.1, which leads automatically to a stabilized population.[122,230,231]

In the three stages, *cultural acceptance* of new laws that enhance energy security (e.g., CO_2 tax) is a necessity.[184] For example, NIMBY movements in some areas[106] threatened wind power advocates[32] and reduced the ability to make new regulations regarding wind energy, solar energy, or nuclear energy, reducing the diversity of the system and thus deteriorating energy security.

The second parameter is *how energy conditions can shape or change cultural behavior*. From the history, it is seen how the discovery of resources changed civilizations and cultures.[135] Disruption of energy production that leaves societies without needed energy cause serious social conflicts,[79] with immediate negative results.[25] Simply having to wait in line to buy gasoline has led some Americans to shoot each other.[65] Wealthy and powerful societies achieve energy security easier than poor ones.[73] Such financial consideration alter energy consumers' purchasing behavior.[114] Furthermore, energy excess will change habits related to energy consumption[87] and affect the social atmosphere in which identity is developed.[228]

The threat to this dimension is the psychological effect.[66] Societies and individuals are manipulated by media, which presents a distorted reality, misleading conclusions, or even wrong facts. Last, one common index to describe the culture dimension is the human development index (HDI).[105]

Literacy

Knowledge and access to information is an important dimension for energy security.[232] As humans are concerned with the energy security of the system, they should know about it. The literacy of energy security has three levels: information should be available (provided or taught), information should be adorned so people will have the desire to learn, and then people use this information in order to achieve energy security. In order to achieve energy security, the literacy should be on different measures: features of the energy system, how the system works, how it affects the society, how it can be improved, and more importantly how to use it securely. Energy literacy gives homeowners more control over their own energy security.[33]

The first parameter is the *availability of information*. Information should be available (provided or taught) in order to promote energy security.[29] Also, the quality of the information matters, high quality information supports energy market to well function,[17] which enhances energy security. Furthermore, it is not enough to have market information alone; public awareness should be priority in order to enhance energy security. Moreover, awareness alone is not the goal, there should be structured educational programs about energy and energy security to supplement the understanding of the system and how to utilize it effectively.[212] For example, the information for end-consumers about which devices are more efficient and which are not.

The second parameter is related to *how the information is presented and how the knowledge is* *spread*. Information should be adorned so people will have the desire to learn. In that way, governmental support for the development of the energy system is needed.[47] Adequate funding of research and development in the field of energy is the way to achieve energy security.[127] Such governmental support and financial support is incentive for people to learn about energy and energy security. For example, introduction of ecolabeling schemes and regulation by the government encourages customers to consider the environmental dimension of energy security in their decisions.[85] Also, disseminating market information enhances energy security[126] by allowing customers to react effectively. The Japanese Top-runner program is one example of presenting the information about energy application and efficient regulations to customers.[233–235]

The last parameter for literacy is the *use of energy information in order to achieve energy security*. In general, individuals with higher levels of education are more likely to have responsible attitudes in regards to energy security.[228] Awareness, knowledge, and education result in trained workers for the energy system to be run securely.[236]

Most of the threats to the energy system in the dimension of literacy are the workforce constraint.[35] That lack of qualified employees might cause many disruptions in the system.[67] Such scarcity of talents affects energy infrastructure development negatively and thus deteriorates energy security.[155] Apart from the workforce constraint, lack of enough market information that allows for competitive consumer decisions can result in energy market failure,[237] with all of the negative impacts on energy security. Lord Nicholas Stern clearly pointed out that 'The existence of climate change is the largest and widest ranging market failure ever seen.'[238] This market failure is a result of poor policy and regulations because of lobbyism and corruption. However, a major part is the lack of needed knowledge delivered to end-customers.

Some researchers suggest public resistance to new power generating units or annual cost of car accidents[36] as indexes for literacy. Others suggest innovation research investment.[142] However, an equally informative index would be the number of courses about energy systems at schools.

Employment

The relationship between energy security and employment is a two-way relationship. Higher unemployment rates can be a result of a less secure energy system. When energy prices skyrocket over the energy poverty threshold (energy security deteriorates), a lot of pressure is put on nominal wages.[25] Thus, a higher unemployment rate may happen.[239] However, different counties might experience the situation differently, so that steadily but moderately increasing energy prices may lead to more innovations in energy efficiency, even increasing the employment and the energy security. When energy security is deteriorated by disruption, many jobs can be lost. For example, in November 1976 in the United States, over a million people were laid out of work in 20 states.[240] The cost of this situation was 435 mUSD_{2016} (100 mUSD_{1976}) in unemployment benefits. Therefore, a more secure energy system may lead to higher employment rates.

On the other hand, the employment rate can affect the energy security. A higher employment rate means revenue generation opportunities for individuals,[170] stronger purchasing power, and more financial resources directed to the energy system.

Furthermore, the employment rate and conditions in each stage of the energy system (people who work in production field or energy transfer) affect energy security. For example, in 2010, there were 9.1 million jobs globally related to the provision of electrical energy alone.[151,241] Having the experts to run the system efficiently is considered to enhance its security. Bad conditions for workers reduce energy security because of more exposure to risks. Finally, employment in the energy sector is a good example for an index for this dimension.[232,242]

Policy

There is a strong relation between policy and energy security,[70] thus, energy security cannot be separated from political interests.[153] Because achieving energy security is an important goal,[51] its concerns affect the way how the decisions are made.[29] Therefore, energy politics will determine our survival as we know it on our planet.[229]

The first parameter is the *relationship between energy security and the political system, its stability and its internal and external relations*. First of all, a solid political structure is needed to achieve energy security.[73] The political system can be located in between two extreme ends; total democracy in which individuals and societies decide for themselves (the decision is made following the citizens' will), to a total dictatorship in which all the decisions are taken by one person, a group, or a party without bearing in consideration the citizens' will.

Theoretically, in democratic systems, majority makes the decisions; with representatives from the different sectors in the society hence ensuring citizens' will.

In such systems, energy security is clearly seen as the responsibility of the state[97] that represents individuals. However, such a system has a threat of being overdominated by one view of energy security resulting in underestimating the other dimensions. For example, if left-wing parties are in power, the social dimensions of energy security will have more importance than the cost dimension. Even within the democratic approach, there are the presidential model and the parliamental model where the decision power is in different hands resulting in different estimation of different dimensions of energy security. On the other hand, in a dictatorship regime, the decision power is with a person or a group, without any representation of citizens' will. Therefore, energy security dimensions that are related directly to the society are typically not considered, resulting in a high probability of losing security grounds for the energy system.

The type of political system affects how the country manages its foreign relationship.[17] The foreign relations range from mutual dependence and cooperation[80] to a total dependence on a certain ally.[243] In many cases, democratic systems seek to benefit their societies when they make their relations, but on contrast, dictators tend to make the relations based on their own interests relying more on similar dictator systems and comforting other nations.[244] In that sense, converging national interests is needed to attain energy security.[92] Such orientation of the political system can result in political interventions from other countries and organizations, either positively or negatively. Embargoes and sanctions reduce energy security,[83] whereas energy treaties and agreements enhance energy security[67] by fostering political strength and stability.

Down the way, after the political system is defined, the second parameter is *regulations* that affect energy security. In general, regulations swing between free markets in which practicalities are determined by market mechanisms (e.g., supply–demand balance) or controlled markets where the procedures are determined by one authority.[114] There are supporters for both sides, for example, Barton[70] argues that, stricter law and more regulations and control enhance energy security, because free markets usually look for short-term profits[67] and produce harmful emissions that lead to the death of citizens. However, on the other side, Chester[26] and Lakić[153] consider liberalization of the energy market to increase energy security, because a regulated market with a lot of subsidies for certain energy services promote irrational use of energy, let alone societal lack of responsibility to use energy efficiently. Nevertheless, less regulated markets promote irrational use of natural resources that leads to harmful emissions and high societal costs.

Supporters of more regulated markets use different arguments, e.g., obligations to hold reserves[243] will create incentives to drive changes in consumption patterns.[229] Such standards can be translated as promotion of certain energy services or technologies[85] to enhance the energy security. On contrast, energy subsidies are considered to be unsustainable energy security policies[155] because they channel investment,[32] specially for fossil fuels. An example of panic resulted from subsidies and its unsustainability is what was seen in 2015 in Mexico and United Arab Emirates in which low oil prices forced subsidy reforms.[245] However, if subsidies are meant to bring the system back into balance like subsidizing clean renewable energy (e.g., solar energy), they can be considered a sustainable option (reforms in Mexico), in particular, all energy technologies had been heavily subsidized during their introduction phase. Although they channel the consumers' choices but that is needed because big oil companies that control the oil industry care about profit more than a sustainable society. For example, there is a 4700 bUSD post-tax subsidies and 333 bUSD (around 5000 bUSD total) of public means annually allocated to subsidize fossil fuels globally (coal is the biggest source of post-tax subsidies then petroleum).[157] This amount of subsidy is used directly and indirectly to channel consumers toward fossil fuel, whereas they could be used in other investments[32] such as new clean technology, improving health and education or improving public infrastructure.

The subsidy is the most important part of the regulated market. As reported by Coady et al.,[157] the subsidy of coal, oil, and gas is not sustainable and reforms should take place. Furthermore, they calculated the benefits in terms of reforms that cut subsidies from fossil fuel. The results show that the world can produce more than 3000 bUSD in benefits for fiscal balances, environment, human health, and economy.

Based on this discussion, our view is that each piece of regulation has to be analyzed separately in order to determine how it affects energy security regardless what market model is to be used. There should be a combination between the two models, a combination that has a mere purpose of enhancing energy security, using such a combination promotes energy security.[114] For example, a free market model does not mean enhancing energy security if it allows the use of coal as a cheap option with all the threats coal holds for environment and health. However, a more liberal market where the cheapest energy option is clean, renewable energy will promote energy security. On the other hand, imposing governmental tariff on energy imports will reduce diversity and hence reduce energy security. However, a ban on building coal-powered electricity generation plants will accelerate the transition for alternative cheaper and cleaner options, which is seen nowadays

The third parameter is the *governance of the system*, how the regulations and the decisions are applied. The implementation of the regulations is meant to enhance energy security.[29] The typical situation to be expected is that the governance follows the regulations determinately. However, sometimes the situation diverges from that situation in two paths: if the regulations are made without the citizens' will, people might pay no heed to the regulations and act in inconsistency with the regulations. For example, people might find climate standards and measures too expensive; especially if they are made by a government that does not represent citizens' will (autocratic systems). The other option is to repeal against elected personals who made the regulations[126] and choose others (democratic systems). Another example is the construction of nuclear power plants in regions where citizens' will is against nuclear energy but supporting renewables. This might lead to less cooperation between the society and such power plants; for example, society might boycott buying electricity from nuclear power plants causing its bankruptcy or force the government to phase out nuclear energy, which happened recently in Germany. The second path is applying the regulations selectively by responsible personals to attain their own benefits.[77] An example of such a corruption that deteriorates energy security is the nuclear waste buried in some African countries. Regulations prevent nuclear waste to be buried in the country but because of the corruptions, some people in high positions manipulated the regulations for a huge payment to allow this waste.

The importance of policy dimension makes its threats and risks a key concern for energy investors.[155] Political uncertainty causes a threat to energy security.[146] Corruption and transparency affect the energy system. Whatever the political system and the regulations are, corruption and intransparency deteriorate energy security.[73] Although, Elkind[126] argues that policymakers and state's officials must be required to take a Hippocratic Oath, hardly, any system is lacking so much transparency as the energy system.[80] In a dictatorship system, energy revenues facilitate corruption, establish privileged links of power, and reduce motivation for good governance resulting in negative impacts on energy security.[229] In a democratic system, the situation is slightly better because the public monitor officials, but even though, many researchers are skeptical about it. Müller-Kraenner[80] claims that 'like oil and water, oil and democracy do not mix well.' They do not coexist.[246] The interests of the energy elite are in many cases against the interests of the population and can lead to policies for their own benefit[153] even in democratic systems. In such cases, the citizens' will is not followed. That is not only a threat for the energy system, but also a threat for the whole social and political system. In Organisation for Economic Co-operation and Development (OECD) countries and in particular in some European countries, there is no clear political executing, regardless the overwhelming citizens' will and strong support to shift into renewable energies as reported by Knebel et al.[247] The reasons are not obvious but may have to do with lobbyism, vested interests, and lack of democratic values.

Leading and driving of the interests of societies is the second major threat for the policy dimension. The use of energy security to promote certain policies is seen as a 'carte blanche' to achieve political goals that fit the elite by whatever means, even military.[77] Leading public opinion to think about an issue affecting energy security in a certain way in order to legitimize the use of military force to attain goals, that could otherwise not be attained, is the concept of securitization.[77] This will be also discussed in the next section. Securitization is a huge threat to energy systems because it makes policy and actions to underestimate other factors, all to satisfy the elite.[106]

Last, some numerical indexes for this dimension are subsidies and standards regulations,[82] transparency indexes, political stability, World Bank's Worldwide Governance Indicator,[40] and energy efficiency standards.[224]

Military

Military is usually used to exercise power in order to achieve certain goals. Energy is crucial in military[84] and their relationship has many parameters to be addressed.

The first parameter is the use of *energy resources for military purposes*. Using jet fuel in air-jet fighters (in average two barrels of crude oil are needed to make one barrel of military jet fuel[240]), electromagnetic lasers in location determination or nuclear energy in nuclear weapons are among the needs of modern military forces. Therefore, having a functional military to protect the energy system and increase the energy security needs a lot of energy. To give an overview of how much energy is needed for military, Smil[248] states that about 5% of all United States and Soviet Union energy consumption between 1950 and 1990 went to weapons' development.

However, the use of energy in the military can reduce the energy security of the system especially if the casualties of that use are big. For example, the use of nuclear weapon in a military operation affects the environment negatively, thus, reducing energy security. Furthermore, as many think war is not the best way to solve humanity's problems, the cost for using energy in conflicts is not justified.

The second parameter is the '*Militarization*' concepts of energy security. Principally, militarization is more involvement of military forces to affect the energy security.[249] Military operations target the energy system as an object to have the wanted effect. Klare[250] argues that a huge competition will take place in 21st century where wars will be fought over resources not over ideology. The case has been that nearly all cross-border wars and civil wars in 21st century that have taken place during the past two generations are due to energy resources.[248] In that way, energy resources are a significant factor causing military conflicts.[127] Therefore, in this parameter, military is used as a mean to serve higher ends[65] by protecting, capturing, or destroying energy system composition (resources, transportation routes, or infrastructure). Although, Deutch et al.[202] argue that energy infrastructure cannot be defended by military means, however, many countries have devoted large resources for securing critical energy infrastructure.[77] In our view, infrastructure still needs to be protected by military forces because it constitutes an attractive target for terrorist acts,[77] as will be discussed later. For example, in 1990, Iraq attacked Kuwait in order to control oil fields[125] and in WW II the Germans attacked the oil shipment lines in the Atlantic Ocean. Another example is the installation of ice breakers to the Canadian navy in order to support its claims about natural energy resources in the Arctic.[80] In that sense, the energy system was the goal of the military operation in order to reduce the security of the opponent or increase the energy security of the attacker.

The third parameter is the *use of energy as a mean in a military conflict to achieve political objectives*.[129] One example is what was seen in the WW II, when the Unites States deliberately restricted energy exports to Japan to force them withdrawing their military forces from East Asia.[125] This concept became to be known as 'Energy Weapon.' Although there is a debate how effective the use of energy weapon is, under certain circumstances, it will achieve its goals.[148] However, nowadays, there is a greater confidence that successful use of energy as a political weapon is relatively limited.[90] Also, sanctions to stop buying energy from specific energy producer can be considered as energy weapon.[90]

The fourth parameter is the *destabilization factor*.[129] Energy systems can destabilize societies resulting in conflicts and military operations taking place. Many points can be seen within the destabilization parameter. The resources curse which was mentioned in the availability dimension can result in military involvement, such as civil wars, unrest, military coups, and governments being forced out, which were seen specially in 1950s in the Middle East because of oil resources.[125] Another point of the destabilization factor is the military involvement as a result of environmental deterioration. A good example is Easter Island where deforestation caused military involvement and violence.[251] Furthermore, terrorism funding[126] using energy revenues for fuelling military conflicts 'Economies of violence'[80] is another point of the destabilization factor, e.g., Iran funding Hezbollah.[36]

When threats and risks on the energy security are to be discussed the first threat to mention is 'Securitization.' Securitization is a theoretical term that is used for energy security nowadays. Securitization is presenting a public issue to be as an existential threat that requires extreme actions out of the political normal procedure.[252] Securitization leads to legitimize the use of military force in order to attain goals that could otherwise not be attained.[77] An example is the issue of oil supply, as the United States saw the continuity of oil supply as a national priority thus deploying its military in the Gulf.

The second threat is terrorism and piracy that impose a huge threat on the energy system.[253] For example, Al-Qaeda threatened to attack global energy critical infrastructure.[17] Terrorist attacks usually have temporary effects and their damage is rapid, but their effect on the economy is vast.[145]

The third threat to the energy security within the military dimension is the impact of postmilitary operations. The remaining of wars is a threat to flora and fauna (deteriorating energy security).[80] Such military operations destroy energy infrastructure, deteriorate health, and damage environment.[32] For example, Soviet and German gas grenades were left after the WW II in the field reducing security of that region.

The last threat within military dimension is its relations to other dimensions. Use of military is always tremendous, expensive, and cause a lot of visible and invisible casualties on the economy, the environment, and the society.[67] Therefore, the exact effect on energy security cannot be always positive. There should be a balance with other dimensions. For example, in the United States, total funding for Iraq reached about 600 bUSD after 6 years of the Iraq war; in comparison to Department of defense homeland security efforts of

50 bUSD.[164] In addition, the estimated cost of American force projection in the Persian Gulf for 1976–2007 is found by Stern[165] to be 6800 $bUSD_{2008}$. Such imbalance between the dimension is debatable whether it pays off the expenses or not.

Energy consumption for military purposes[248] or military expenditures[165] can be numerical indexes for this dimension.

Cyber Security

As nowadays all energy infrastructures depend on the digital support[184] with future prediction of more digital devices,[254] the digital dimension is important for energy security. Although, the paradigm is of another nature than the physical one, cyber security affects the physical energy system severely. The importance of this dimension, though rarely discussed in literature, is uncountable. Computers and digital programs control the whole energy system (production, connections, and consumption).[254] Destruction in the cyber dimension can cause tremendous economic loss.[202] Even anticipation for disruption such as the common Y2K computer bug of January 1, 2000, can do the same.[17] Therefore, any failure in the cyber dimension will cause a certain impact on the system.

The first parameter of cyber dimension is *connectivity*. Because energy systems are controlled by automated digital programs[93] and are connected to the internet.[254] In addition to self-failure, cyberattacks on energy systems are growing[255] and thus cyber security is becoming a pacing issue.[93] Such cyberattacks are easier and safer than causing the same harm by physical attacks.[256] Digital programs of the energy infrastructure are an attractive target for terrorists because they are 'soft,' easily destroyed, or incapacitated by a cyberattack.[202]

The second parameter is the *software being used*. Supervisory control and data acquisition (SCADA) and industrial control systems (ICS) have real-time control and monitoring of energy facilities and equipment but they are vulnerable to threats.[155,202] In many cases, failures of the digital system are self-failures as what happened for Soviet natural gas pipeline in Siberia.[87] The huge blast and detonation of the pipeline was thought a nuclear explosion. However, after the investigation, it turned out, there was a malfunction in the computer control system. On contrast, in many cases, the system failure is caused by virus attacks. For example, in January 2003, the Davis-Besse nuclear power plant in Ohio was offline for 5 hours because of a virus attack on its SCADA system.[32] Another example is what was reported by Shalal[257] that some power plants in South Korea and in Germany have been targets for disruptive cyberattack.

For this, the last parameter is the *information technology (IT) skills, how to keep a system functioning against the cyber threats and attacks*? The more secure the digital system is, the more secure the whole energy system is. But how to achieve that? Escribano Francés et al.[256] refer to a main point: the IT skills. Thus, if the skills are exploited in designing the system, energy systems will enable real-time monitoring, decision optimization, and remote control.[258] On the other hand, if the skills are available for the attackers, the energy systems will be vulnerable, for their control computers being disabled, for their instruments being rested or for the calibrations being biased as pointed out very early by Lovins and Lovins.[240] Examples of skilled attackers targeting the energy system are many: Lithuania faced a cyber assault by pro-Russian hackers in 2008 because of its unilateral veto on an EU energy partnership deal with Russia,[259] the 2014 cyberattack on the nuclear power plants in South Korea,[260] the Shamoon cyberattack in 2012 on Saudi Aramco, the largest oil producer in the world,[255] and attacking Iranian nuclear facilities with 'Stuxnet.'[261]

When it comes to threats and risks of this dimension, there is a lot of improvement needed in the system. Many parts of the transmission and distribution grid system were 'developed' without concern for cyber security.[262] For example, smart meters were developed to cope with the development of smart energy systems e.g., smart grid; however, many consumers and service providers have shown concerns about their information security. In the smart grid systems, the most vulnerable part is the transmission part,[263] in which meters are easily vulnerable to hackers' attacks.[264] Also, there seems to be a low level of awareness of the resulting impact of the cyber threats.[155] And the system vulnerabilities of SCADA systems are highly underestimated, rarely disclosed, and the incidents affecting them are hardly reported.[32] Finally, an example for indexes that can be used to evaluate the cyber security of a system is the rate of cyberattacks on a certain system or the economic losses resulting from a specific attack.

CONCLUSION

After this exploratory dive into energy security, this paper tracked the definition of energy security along

TABLE 1 | Summary of Energy Security Dimensions and Parameters

Dimensions	Parameters
Availability	Existence of resources
	Existence of consumers
	Existence of means of transport (access)
Diversity	Diversity of sources
	Diversity of fuel (energy carriers)
	Diversity of means (technologies, transportation)
	Diversity of consumers
Cost	Energy price (consumers, producers, pricing system/subsidies, energy poverty, peak oil, and stability/volatility)
	Cost of disruption
	Cost of securing the system
Technology and efficiency	New technology advancement
	Energy system efficiency
	Energy intensity
	Energy conservation
Location	Energy systems boundaries
	Location of energy source
	Density factor (centralized/decentralized)
	Land use
	Globalization
	Population settlement and distribution
	Geography
	Industrial intensity
Timeframe	Timeline
	Length of the event
	Length of the effect (struggle or impact)
Resilience	Adaptive capacity
Environment	Exploration rate and resources' location
	Extraction and transportation methods
	Outcomes from energy use
	Impact resulting from environmental change
	Relationship to water
Health	Impact of people's health on the energy system
	Impact of the energy system on health of (energy sector workers, consumers, and international society)
Culture	Cultural effect on the energy system [production, connection, consumption, cultural acceptance (NIMBY, Not In My Back Yard)]
	Energy conditions shaping cultural aspects
Literacy	Information availability (quality, market information, public awareness, and structured educational program)
	Information presentation and provision
	Usage of energy information
Employment	Effect of energy security on unemployment rate
	Effect of employment rate on energy security
Policy	Political system, democracy/dictatorship (nature, stability, citizen's will, and internal and external relationship)
	Regulations (liberalized and controlled market, rules, and subsidies)

(*continued overleaf*)

TABLE 1 | Continued

Dimensions	Parameters
	Governance (flowing the rules (transparency), following the rules selectively, not following the rules, corruption)
Military	Energy use for military purposes
	Militarization
	Energy as a mean in a military conflict (energy weapon)
	Destabilization factor (resources curse, environmental deterioration, and economies of violence)
Cyber security	Connectivity (Cyberattacks)
	Software use (Supervisory control and data acquisition, SCADA, program failures)
	IT skills

the history through scientific literature review as summarized in Table S1 of the Appendix S1. In total, there were 66 different definitions, found in 104 literature sources (peer-reviewed papers, scientific journals, and books). In tracking the definition of energy security, it was obvious that the repetition of some definitions in many places, implying a wider acceptance for some definitions than the others. However, the conclusion out of the literature was that there is no consensus about how to define energy security or what to be included in the discussion. Therefore, the efforts were not constrained on the literature review of the definitions but rather continued to formulate a definition that is generic enough to be applied in the present with the lessons from the past that leads to be accepted by other researchers for the future. The adopted definition for energy security is 'the feature (measure, situation, or a status) in which a related system functions optimally and sustainably in all its dimensions, freely from any threats.'

Based on this definition, in order to have a sustainable energy system that functions optimally, its dimensions and threats should be identified. It is the second part of this paper. Energy security dimensions were identified and designed to cover all the different aspects in energy security. In total, this article concludes the need to include 15 different dimensions (Availability, Diversity, Cost, Technology and Efficiency, Location, Timeframe, Resilience, Environment, Health, Culture, Literacy, Employment, Policy, Military, and Cyber Security) if energy security is to be addressed perfectly. These dimensions were tracked in the same literature that energy security definitions were studied and summarized in Table S1 of the Appendix S1. Figure 2 represents the occurrence, frequency of each dimension in these literature sources as summarized in Table S2 of the Appendix S1. It is obvious that, availability, cost, and policy were the main three dimensions that were present in most of the literature. On the other hand, cyber security was the least to be discussed when it comes to energy security, though it is one of the most important dimensions nowadays. This leads us to the conclusion that cyber security did not have its sufficient discussion within the energy security discussion. It can be concluded that although the energy system is nothing without people, social-oriented dimensions (health, culture, literacy, and employment) experienced less coverage by the discussion about energy security. Another important point to stress on is the absence of any literature that identified all the 15 dimensions, proving the novelty of this identification this paper has. The conclusion is that each one of them discussed energy security partially without addressing all the dimensions, as they needed to be addressed.

As discussed throughout the course of this paper, each dimension has different parameters that attribute to that specific dimension. The summary of each dimension and its parameters is presented in Table 1. Furthermore, the discussion of each dimension went on to determine the threats on energy security that are related to each dimension. Last, some numerical indexes were represented for each dimension.

This overview of energy security with all of the discussed topics provides recommendations for policymakers, governments, and researchers. In order to come up with inclusive and comprehensive agenda for energy security, all the 15 dimensions and their parameters should be taken into account. The exclusion of any of these dimensions will result in an imbalanced outcome and decisions in regards to energy security because all the dimensions are interdependent and can affect each other.

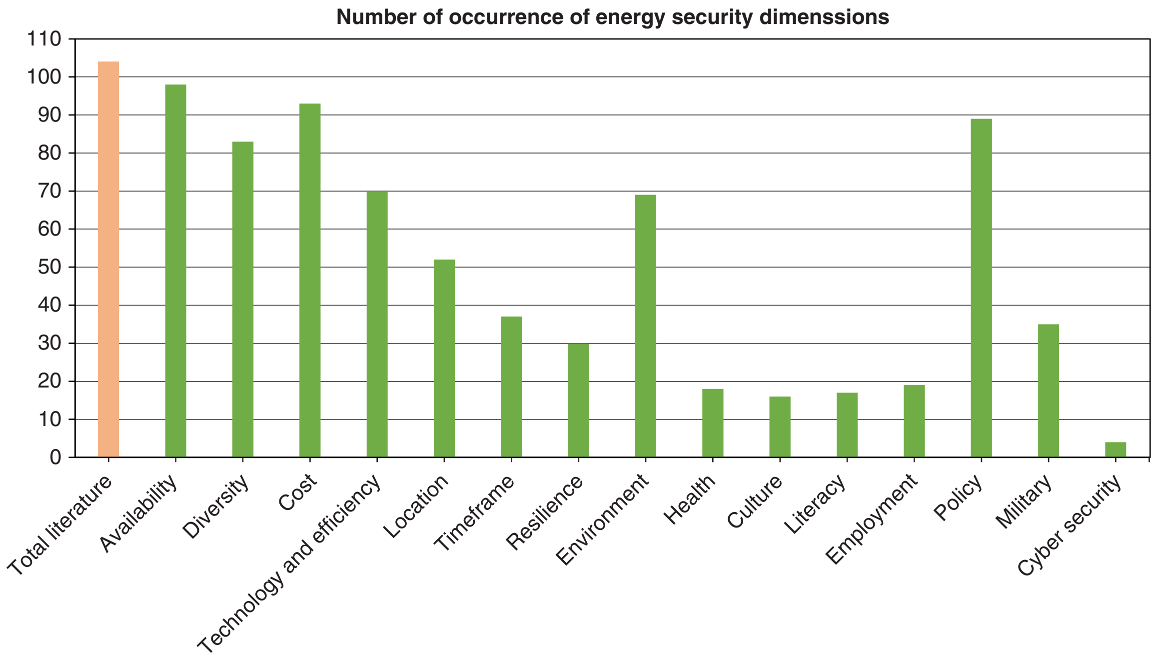

FIGURE 2 | The frequency of different dimensions mentioned/discussed in literature.

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