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Environmental and Renewable Energy Aspects of Energy Security

Postgraduate Student Name: ELENI PSAROUDAKI

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Η Ελένη Ψαρουδάκη δηλώνω ότι: το έργο που εκπονήθηκε και παρουσιάζεται στην υποβαλλόμενη διπλωματική εργασία είναι αποκλειστικά ατομικό δικό μου. Όποιες πληροφορίες και υλικό που περιέχονται έχουν αντληθεί από άλλες πηγές, έχουν καταλλήλως αναφερθεί στην παρούσα διπλωματική εργασία. Επιπλέον τελώ εν γνώσει ότι σε περίπτωση διαπίστωσης ότι δεν συντρέχουν όσα βεβαιώνονται από μέρους μου, μου αφαιρείται ανά πάσα στιγμή αμέσως ο τίτλος.

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1. Introduction

1.1 Preamble

Energy is a crucial commodity that affects every aspect of a functioning modern society in human life and the development of economies as well. So, the question of how to secure energy is an essential one. Energy security is implicitly considered as a synonym for security of supply, especially by scholars implementing an economic perspective. Energy security is also linked with national security with a major focus on fossil fuels -especially oil- and on their military role in ensuring or preventing access to energy resources.

Plenty of studies research energy security from various angles of different countries and compare different methods and assessments during different periods. Nevertheless, no matter how energy security is defined, a thorough comprehension of both the complexity of interconnected environmental issues and the related social and economic concerns is essential.

The notion of energy security keeps evolving, expanding and changing with political, social and economic indications along with changes in other fields of development, geopolitics, economic transition and environmental security. Thus, it represents the great challenges that humanity faces in the 21st century, including the environmental aspects. Climate change and local air pollution are among the critical factors for energy transition globally.

Renewable energy is estimated as a game changer in terms of energy security; consumer countries have become producers; producer countries have become consumers; and the role of transit countries has changed. In addition, economic growth, foreign direct investment, trade openness and emissions of carbon dioxide create the necessary stimulus for the development of renewable energy. The use of renewable energy sources increases the level of energy security, mitigates climate change by reducing the greenhouse effect, promotes regional development and creates new workplaces. Meanwhile, renewable energy turns countries more resistant to geopolitical conflicts and more independent of the vagaries of fossil fuel markets.

However, there is no form of energy production or use without environmental impact. Renewable energy sources have environmental benefits in comparison with conventional sources, though they are not free of negative impacts. Despite the negative environmental impacts and any social acceptability issues, renewable energy sources induce considerably less environmental impacts than fossil resources and they are regarded as a better alternative considering conventional energy systems and environmental sustainability.

Considering the above, the goal of the thesis is to examine the energy security implications of renewable energy and environmental sustainability and essentially to determine the contribution of renewable energy to the energy security dimensions.

1.2 Structure of the thesis

This thesis constitutes a literature review of Environmental and Renewable Energy Aspects of Energy Security.

Chapter 2.2. Energy security provides a historical overview of the notion of energy security and how the concept has evolved over the years along with the transition of the world's energy regime. Afterward, the conceptualization of the notion of energy security is presented in reference to the dimensions and the components of energy security following international literature.

Chapter 2.3. Energy security and renewable energy addresses the role of renewable energy in energy security, presenting initially the increasing interest in renewable energy and energy transition, followed by the analysis of the four dimensions of the contribution of renewables to energy security. Additionally, the impediments of renewable energy sources are also the focus of this chapter.

Chapter 2.4. Energy security and the environment presents how energy security affects the environment and vice versa. More precisely, this chapter examines the environmental impact of the most important renewable energy technologies. Finally, Chapter 3 includes the conclusions of this thesis.

2. Literature review

2.1 Introduction

Process of literature selection was conducted with the purpose of finding the most relevant and important publication, by using the keywords ‘energy security’, ‘energy security dimensions’, ‘energy security indicators’, ‘renewable energy’, ‘environmental impacts of renewable energy resources’, ‘life-cycle assessment’. The most used sources were the internet platforms ‘Google’, ‘Google Scholar’ and ‘ScienceDirect’. The findings were scanned appropriately to include publications and research that focuses on defining energy security and its historical evolution, and the environmental and renewable aspects of energy security. Considering that the issue needs to be approached holistically, studies and research that include different countries, regions and based on different methodologies and examples are accepted, compared and assessed within the scope of this thesis.

2.2 Energy Security

In this section the main aspects of energy security are presented. To be precise, the central point of this chapter is the examination of the evolution of the concept of energy security through the years, followed by the attempt to understand the notion of energy security. For this purpose, a historical background of the concept is given. Finally, the dimensions and the components as they are referenced in international literature, are presented.

Energy security is defined by Abdullah et al (2020) as “a multi-dimensional concept”, while Chester (2010) states that the concept of energy security is “inherently slippery”, due to “its polysemic nature”, with numerous dimensions and distinct fields of studies relying on the energy source, period, country, region or continent to which it is referred. Hence, the notion of energy security has been defined in the literature, as “abstract, elusive, vague, inherently difficult and blurred” (Chester 2010; Azzuni & Breyer 2017). According to Chester (2010), the restricted examination of the nature of energy security and its terms emphasizes geopolitics and the security of supply of primary sources. In addition, Irie (2017) states that energy security was initially comprehended as “a stable supply of energy” predominantly oil, since oil has been the most significant energy resource, “against geopolitical risks such as conflicts between or within nation state(s)”. Moreover, Johansson (2013 a) mentions that energy security is frequently utilized, especially in academic research "as a synonym for security of supply" with an economic approach. The term energy security is firmly connected with national security and is exceptionally affected by fossil fuels, especially oil (Nyman 2015; Paravantis et al. 2019). According to Mulligan (2010), experts and analysts have extensively considered energy, mostly oil, as a matter of national security and have underlined the role of armed forces to guarantee or prevent access to accepted energy resources. Energy security is also strongly linked to microeconomic and macroeconomic growth (Paravantis et al. 2019). Nyman (2015) claims that in the United States of America, energy security is substantial for economic and national security. Thus, energy security continues to be a policy priority.

The concept of "Energy Security" according to Mansson et al. (2014) generated interest in academia along with policy makers. Although the significance of the concept has changed gradually and among different fields, several matters have been kept tightly on the agenda (Mansson et al. 2014). For instance, the inferred threats to national security, because of reliance on scarce oil producing areas and supply lines, have been a matter of interest since the early 20th century, not only for politicians but also for scholars. Since energy security became barely synonymous with 'security of oil supply', natural gas and renewable energy gained ground as alternative energy carriers (Mansson et al. 2014).

2.2.1 A historical perspective

In order to interpret the term energy security, it is useful to mention how the concept of energy security evolved over the years and along with the transition of the world's energy regime.

According to Valentine (2011), the notion of energy security is "as old as fire". Humans in the Early Stone Age perceived the sentiment of energy security as they had to secure the source of flammable material, wood (Valentine 2011; Azzuni & Breyer 2017). As the process of human evolution has occurred the concept of energy security became more complicated (Azzuni & Breyer 2017).

Energy security rose as a policy problem, in the early 20th century, in the form of concern over supply of oil for armies (Cherp & Jewell 2014). According to Hache (2018), World War I was related to the disposal and ensuring of crude oil supply. The hunt for energy sources composed a significant diplomacy component, which led to the 1930s and World War II (Hache 2018). After the end of World War II, the concept of energy security remained inextricably linked to the supply of fuels for the armed forces. The prominence of oil for the military didn't lessen even in the post-war period, though it became crucial for industrial societies and developed nations (Cherp & Jewell 2011).

According to Irie (2017), the conceptualization of energy security arose from the oil supply unreliability in Europe during the Suez Crisis in 1956. In that period several countries became crucially dependent on Middle East oil, mostly those who composed the Organisation for Economic Cooperation and Development (OECD) (Chester 2010). The creation of the Organization of the Petroleum Exporting Countries (OPEC) which occurred in 1960, denoted that the ownership of a power source could be utilized not only as a political weapon but also as a power instrument (Hache 2018).

Literary concern about energy security stemmed since the 1960s and fully developed with the oil crises of the 1970s (Cherp & Jewell 2014) triggered by the OPEC's constraint on production (Hache 2018). Until then, oil remained quite plentiful and inexpensive. The scarcity in global energy supplies incited the constitution of the International Energy Agency (IEA) in 1974 (IEA 2011), by the countries of OECD, with member countries being required to hold oil stocks for sharing in case of emergency (strategic petroleum reserves) (Chester 2010; Hache 2018). The main goal of the IEA has been the assurance of energy security (IEA 2011). So, in the beginning, IEA concentrated only on oil supply security (IEA 2011). This first oil crisis revealed the vulnerability of dependent countries to price fluctuations due to oil shocks (Paravantis et al 2019). In the aftermath, energy security obtained a new view through the requirement to reduce dependence on oil consumption (Chester 2010).

From the late 80s to the 90s scholarly interest decreased with infrequent publications, as oil prices became firm and the peril of political embargoes diminished (Cherp & Jewell 2014; Azzuni & Breyer 2017), and as the energy demand had been reduced (Paravantis et al 2019). Meanwhile, in the 1980s the requirement for broad competition and restriction of governments' intervention in network sectors such as electricity, gas and telecommunications, and traditional government monopolies led to the liberalisation of the energy market with the contribution of organizations such as the International Monetary Fund, the World Bank, the OECD and the support of international trading agreements as General Agreement on Tariffs and Trade and the subsequent General Agreement on Trade in Services (Chester 2010). According to Paravantis et al (2019), during that period global oil imports were reduced by 25% and oil was partially substituted by natural gas and nuclear energy, notably for power generation. Before the end of the 70s, 25 countries such as France, the USA, Germany and the former Soviet Union were generating electricity from nuclear power (Paravantis et al. 2019). In the early 1990s, a period distinguished by the First Gulf War and the collapse of the Soviet Union, the notion of energy security was enriched with new concepts and gained greater importance worldwide, while global resources got deficient confronting the growing global energy demand (Paravantis et al. 2019).

In the 2000s, the academic concern on energy security reignite as a major issue due to the following reasons: the augmented energy cost, the reliance on energy of industrialized economies for economic and social prosperity and development, the disruption of gas supplies in Europe, the significant interruptions in oil markets, associated with armed revolution and the global crisis in energy supply, the complexity of global markets, the competition for energy sources and the political conflict, the increasing energy demand in Asia, climate change and the decarbonization of the energy systems, threats to energy system and the mentality considering energy security comparable to national security (Cherp & Jewell 2014; Azzuni & Breyer 2017). In fact, the rise of China and India in the late 20th century, transformed them into main energy consumers and major energy importers leading to an increase in their consumption from less than 8% of the world's energy consumption in 1980 to 18% in 2005 and over the next 25 years. Chester (2010) predicts that their energy consumption will be more than double reaching 25% of the world's consumption. The rise in energy demand occurs in line with the increase in the population as well as a higher level of economic activity (Shah et al. 2019). The world's energy demand according to Shah et al. (2019) is expected to be augmented by 145% in 2030 and to double by 2050.

Energy security is interconnected with a broad diversity of components that are affected dissimilarly during different time periods and in different regions. The magnitude of these components alters gradually and depends mainly on the precedences of the national economy to which energy security refers at a certain time (Podbregar et al. 2020). Aiming to attain energy security, several countries are formulating specific energy policies (Podbregar et al. 2020).

The framework of energy security that emerged from the 1973 crisis emphasizes mostly how to control and operate any interruption of oil supplies from exporting- producing countries (Yergin 2006). Currently, the notion of energy security, according to Yergin (2006), requires to be expanded and to comprise the protection of the whole energy supply chain and also the protection of infrastructure. Cherp and Jewell (2014) claim that contemporary and 'classic' energy security studies are significantly different. In the 70s and 80s, energy security was signified as a stable supply of inexpensive oil, beneath menaces of embargoes and price manipulations. On the contrary, the current energy security concept needed to be expanded besides oil supplies and to include a broad range of issues such as energy policy issues and mitigating climate change (Cherp & Jewell 2014). In addition, according to IEA (2011), current energy security policies should cope with a wider gamut of risks that arise from the diversity of natural, political and economic factors, more complex than initially, affecting energy sources and infrastructures.

Because resources are gathered in a comparatively few states, lots of other states are dependent on operational global markets and the perpetual accessibility of imports (Mulligan 2010). Therefore, energy security has focused on reliance on supply, prices and the intimations of strategic treating of energy as a "weapon" for the military, industrialized and economic security of states (Mulligan 2010). Podbregar et al. (2020) also state that only a small number of countries reserve energy resources. So, the already perplexing geopolitical relations become more complicated as the energy consumption persistently increases, leading to actions such as the establishment of sanctions, hostilities and tensions along with armed conflicts (Podbregar et al. 2020). Ensuring energy security is the main argument, mentioned by Podbregar et al. (2020), for the justification of determining specific policies which have extended consequences unrestricted to the energy sector.

At the beginning of the 21st century, according to Irie (2017), three significant events have changed and extended the definition of energy security, although the main content of energy security remains the security of energy supply. These incidents, as mentioned by Irie (2017), are the September 11 attacks in 2001, the Russia-Ukraine gas dispute through 2005-06 and Hurricane Katrina in 2005.

The September 11 attacks in 2001 indicated that national security can be threatened not only by nation states, but also by "violent non-state actors" (Irie 2017). Therefore, energy security as a constitutive part of national security, is obliged to confront terrorists or violent non-state actors. Possible targets for terrorists, apart from oil trade, can be considered not only other energy supply systems such as electricity supply, but also nuclear power stations and other similar facilities or installations. As information and communication technology has extensively evolved in energy supply systems, cyber attacks have been an important threat to security (Irie 2017). Hence, new concepts of 'nuclear security' and 'cyber security' have emerged (Irie 2017). So, these three new components were appended to the definition of energy security (Irie 2017).

Furthermore, the Russia-Ukraine gas dispute in 2005-06 led to a supply scarcity of natural gas in Europe (Irie 2017). Even if the world's dominant fuel continues to be oil, natural gas has turned out to be an additional significant fuel for power generation and for heating, which dissimilar to oil, is extremely complicated to stockpile and hence, natural gas has turned into a substantial concern for energy security (Irie 2017). Gas is mostly sold based on long-term bilateral contracts and transmitted through pipelines, passing through various countries (Paravantis et al. 2019). Since Ukraine's independence in 1991 energy security has played a pivotal role in Russian-Ukrainian relations. Two significant crises took place in 2006 and 2009, when Russia terminated the gas supply through Ukraine, the primary “energy-transition country” of Russian gas to the EU (Paravantis et al. 2019). Half of Russia’s total gas which is exported to the EU is transported via the pipeline system of Ukraine and thus Ukraine is an essential component in the global energy field (Paravantis et al. 2019). The Russia-Ukraine gas disputes became a turning point in energy security aspects, as these conflicts according to Paravantis et al. (2019), revealed that the principal supplier of the EU “was not only unreliable, but capable of using energy resources as a geopolitical weapon as well”. Therefore, this substantial reliance on a single foreign energy supplier exposed the EU members to supply interruption or infrastructure failure (Matsumoto et al. 2017). Matsumoto et al. (2017) mention that after the Ukraine crisis, the European Union has attempted to broaden its energy suppliers by augmenting the penetration of renewable energy in electricity production and by exploiting the “shale gas revolution” in the USA and the commercialization of natural gas mostly liquefied natural gas. According to Matsumoto et al. (2017), the European Commission declared its Energy Security Strategy in May 2014 as a response to potential supply interruptions, applying the “solidarity principle” among EU member states which obliges EU countries to help bordering countries going through a gas supply shortage. This strategy aimed to reinforce the energy security in the EU, a firm and sufficient energy supply, by generating an internal energy market, incorporating mislaid infrastructure links, reinforcing emergency procedures for protecting crucial infrastructure, and enhancing energy efficiency (Matsumoto et al. 2017).

Moreover, according to Irie (2017), the third event that changed the definition of energy security in the 21st century is Hurricane Katrina which occurred in the Gulf of Mexico in the United States in 2005 and caused severe damage on crude oil production and petroleum refining facilities. Therefore, the U.S. Department of Energy delivered and used its strategic petroleum stockpiles (Irie 2017). The IEA also demanded the release of members’ oil reserves as the Initial Contingency Response Plan (Irie 2017). Thus, natural disasters were identified as a “threat to energy security” (Irie 2017). In contrast to the terrorism mentioned above, natural disasters are not categorized as a geopolitical risk. That is an additional type of hazard attached to the concept of energy security (Irie 2017). As claimed by Irie (2017), energy security has been threatened by natural disasters in several countries where significant damages caused in energy infrastructures and facilities such as the Great East Japan Earthquake in 2011, as well as the Fukushima Daiichi nuclear catastrophe, Hurricane Sandy in 2012 in the United States and the Super Typhoon Haiyan in 2013 in the Philippines. Hence, ‘energy resiliency’ is one of the proposed policy targets for the Asia-Pacific Economy

Cooperation (APEC), emphasizing the physical firmness and strength of energy infrastructure against man-made and natural catastrophes (Irie 2017).

Therefore, in the 21st century, the accessibility to energy sources relies on a complicated system of “global market, vast cross-border infrastructure networks, a small group of primary energy suppliers, and interdependencies with financial markets and technology” and often depends on the confrontation of the effect of political unreliability and extensive natural events (Chester 2010).

According to Kisel et al. (2016), in the liberalized energy markets, it is quite tough to forecast the energy mix of power production, in particular when there are powerful interconnections to bordering countries where a significant volume of power is imported or exported or when there are other variable power systems such as hydro, participating in the power production. Still more complicated is to foretell the geopolitical or national political changes, which can affect national energy security (Kisel et al. 2016). Under the prism of such a multi-dimensional concept, it is essential to conceptualize and to understand the notion of energy security.

2.2.2 Conceptualizing energy security

This section intends to extensively present the concept of energy security through its main aspects and definitions before the presentation of its dimensions and its components.

Energy security resumes evolving, expanding and changing with political, social and economic indications mostly in the developed world (Abdullah et al. 2020). Supranational organizations demonstrate energy security in their policies. These organizations, as mentioned by Abdullah et al. (2020), are the OECD, the European Commission (EC), the North Atlantic Treaty Organization (NATO), the World Economic Forum (WEF), the Asia Pacific Economic Cooperation (APEC), the G8 and the Association of Southeast Asian Nations (ASEAN). While numerous countries such as the USA, China, Japan, the European Union (EU), Russia, India, Indonesia, Malaysia, Thailand and African nations, use substantial assets to develop energy strategies (Chester 2010; Abdullah et al. 2020). So, it is essential to comprehend the dimensions of energy security along with environmental and economic policies, production installations, distribution and supply and demand side efficiency (Abdullah et al. 2020). Therefore, energy security, as mentioned above, is a multi-dimensional concept including issues beyond the availability of fuel supplies (Abdullah et al. 2020). Abdullah et al. (2020) state that there is not only one definition of energy security; however, in whatever manner energy security is defined it is essential to “an in-depth understanding of both the complexity of interlinked environmental, social and economic issues”. Table 1 provides the definitions of energy security as defined by international organizations, according to Abdullah et al. (2020)

Table 1: Energy security defined by international organizations (Abdullah et al. 2020).

Organization	Definition
International Energy Agency (IEA)	‘‘Uninterrupted physical availability of energy at a price that is affordable, while respecting environmental concerns’’.
Institute of Energy Economics, Japan (IEEJ)	‘‘Energy security means to secure adequate energy at reasonable prices necessary for the people’s lives, and economic and industrial activities of the economy’‘.
Asia Pacific Energy Research Centre (APERC)	‘‘Adequate energy supplies at reasonable and stable prices to sustain economic performance and growth. APERC assess energy security in terms of availability, accessibility, acceptability and affordability’‘.
World Bank (WB)	‘‘Sustainable production and use of energy at reasonable costs in order to facilitate economic growth and improve the quality of people’s lives’’.
United Nations Development Program (UNDP)	‘‘Continuous availability of energy in varied forms, in sufficient quantities and at reasonable prices’’.

The IEA interprets energy security as “the uninterrupted availability of energy sources at an affordable price”. According to IEA, there are plenty of aspects of energy security classified as long-term and short term. Long-term energy security mostly copes with appropriate investments for securing energy supply in accordance with economic growth and environmental requirements. On the other hand, short-term energy security concentrates on the capability of the energy system to respond immediately to abrupt variations in the supply-demand balance (Hache 2018).

As it mentioned above, energy security is defined in the literature by broadly different and occasionally inconsistent definitions. This occurs to an extent, according to Ayoo (2020), due to the different scopes of various authors who have focused on this subject and through their conducted studies varied in the gamut of the impacts of potential risks.

Cherp & Jewell (2011) state the three perspectives on energy security: the ‘sovereignty’ perspective based on political science, the ‘robustness’ based on natural science and engineering and the ‘resilience’ based on economics and complex systems analysis.

The ‘sovereignty’ perspective on energy security is related to strategic security studies, political science and international relations theories and concerns issues of oil security, firstly for military purposes and then for transportation (Cherp & Jewell 2011). The major threats that arise from this field, according to Cherp & Jewell (2011), are malevolent exercise of market power, embargoes and sabotage or terrorism actions. Therefore, strategies for minimizing the risk within this perspective, embrace changing to more reliable suppliers or decreasing a ‘single agent’s role’ via diversification of supply (Cherp & Jewell 2011).

The ‘robustness’ perspective focuses on guaranteeing the steady function of progressively complex systems through the agency of computer modeling and profound knowledge of natural and engineering and technical sciences (Cherp & Jewell 2011). Energy security threat from this perspective is considered as an ‘objective’, abundantly measurable component that includes an increase in demand, deficiency of resources, ageing of infrastructure, technical malfunctions or extreme natural phenomena (Cherp & Jewell 2011). Reducing risks from this angle includes upgrading infrastructure, transitioning to more sufficient energy sources, embracing reliable technologies and coping with the increase in demand (Cherp & Jewell 2011).

At last, the ‘resilience’ perspective concerns the practical difficulties of implementing the operation of energy markets and confirming investment effectiveness in energy systems and technologies inspired by economics and complexity science (Cherp & Jewell 2011). Cherp & Jewell (2011) mention the existence of distinguished complexity, unpredictability and ‘non-linearity of energy systems, markets, technologies and societies, making risks extremely volatile taking into account regulatory modification, unpredicted economic crises, political regime alteration, disturbing technologies and climate variations. Hence, the resilience perspective does not emphasize analyzing these innately unpredictable risks, yet it investigates common traits of energy systems such as flexibility, diversity, adaptability (Cherp & Jewell 2011).

Proskuryakova (2018) points out four energy security concepts that prevail in the International relations theory: neorealism, neoliberalism, constructivism and political economy. Each of them presents a different perspective on the key energy security elements, players and priorities. Despite different approaches, Proskuryakova (2018) states that all the case-studies countries are equally attempting to ameliorate their energy security by augmenting energy efficiency, lessening the vulnerability of the energy system and improving power grid stability, intending to resource self-sufficiency at the national and regional level. The author also claims that in certain cases stability is more significant for energy security than other indicators, as economic and environmental costs.

According to Johansson (2013 a), the relationship between energy and security, based on his broad typology of energy and security, has two approaches that differ in principle: whether the energy system is an object exposed to security threats, or a subject generating or enhancing insecurity. As an object, the focus lies on securing the functionality of the energy system (security of supply and security of demand). The approach to the energy system as a subject generating or enhancing insecurity can in turn be divided into three different types of risk areas: economic-political, technological and environmental (Johansson 2013, a).

Energy security can be also classified into security of supply and security of demand, or physical security, such as uninterrupted supply, price security and geopolitical security (Paravantis et al. 2019). According to Paravantis et al. (2019), in the literature, the term of energy security is linked to the security of supply and is usually utilized as a synonym for the security of energy supply, notably by scholars embracing an economic perspective. Novikau (2021) states that the supply-side-centered perspective of energy security indicates the concern of industrialized countries only, ignoring the energy systems of energy exporters. However, energy security signifies different aspects to different countries, determined by “their geographical location; their natural resource endowment; their economic disposition; their status as producer/exporter, consumer/importer, or transit; their vulnerability to energy supply disruptions; their political system; their ideological views and perceptions; and the status of their international relations” (Paravantis & Kontoulis 2020). Du et al. (2020) having evaluated energy security in 30 countries, also claim that the energy security level of each country is intertwined with “its resources endowment, energy technology and national policy”.

The position of a country in the energy market, in the case of a producer/exporter, a consumer/importer, or a transit country, defines the country’s energy security goals (Paravantis & Kontoulis 2020). Producer/exporter countries attempt to secure a stable demand, while the goal for consumer/importer countries is the diversification of energy supply, in order to reduce their reliance and increase their security. On the other hand, transit states play the role of “bridges” linking producer/exporter countries and their markets (Paravantis et al. 2019; Paravantis & Kontoulis 2020). Furthermore, according to Paravantis et al. (2019), for consumer and transit countries the security of supply is significant, while, for producer/exporter countries security of demand is perhaps as significant as security of supply (Paravantis & Kontoulis 2020).

Although energy security is a concept that includes environmental sustainability, economic competitiveness of energy and a broad range of geopolitical matters, the literature mostly concentrates on “the uninterrupted physical availability of energy at an affordable price” (Paravantis et al. 2019). Sovacool & Brown (2010) point out the three pillars on which energy security is based: energy efficiency, diversification of supply and reduction of price volatility. Goldthau & Sovacool (2012) mention the three ‘key energy challenge’, energy security, energy justice and low carbon transition, in an energy system. Yao & Chang (2014) state that the most commonly cited definition of energy security is “a reliable and adequate supply of energy at reasonable prices”. The three above components of energy security, according to Yao & Chang (2014), encompass the two main dimensions of the notion: economics and technology. However, there is also a third dimension- the environmental one, as protection and consideration for environmental deterioration (Yao & Chang 2014).

Ang et al. (2015) point out the concept of “energy trilemma" as an endeavor to a holistic approach to energy security and its competing goals at a national or supra-national level. Energy trilemma according to Ang et al. (2015) is depicted as balancing the trade-offs between the three significant energy goals: energy security, economic competitiveness, and environmental sustainability. Figure 1 illustrates how these energy goals overlap under the prism of energy trilemma.

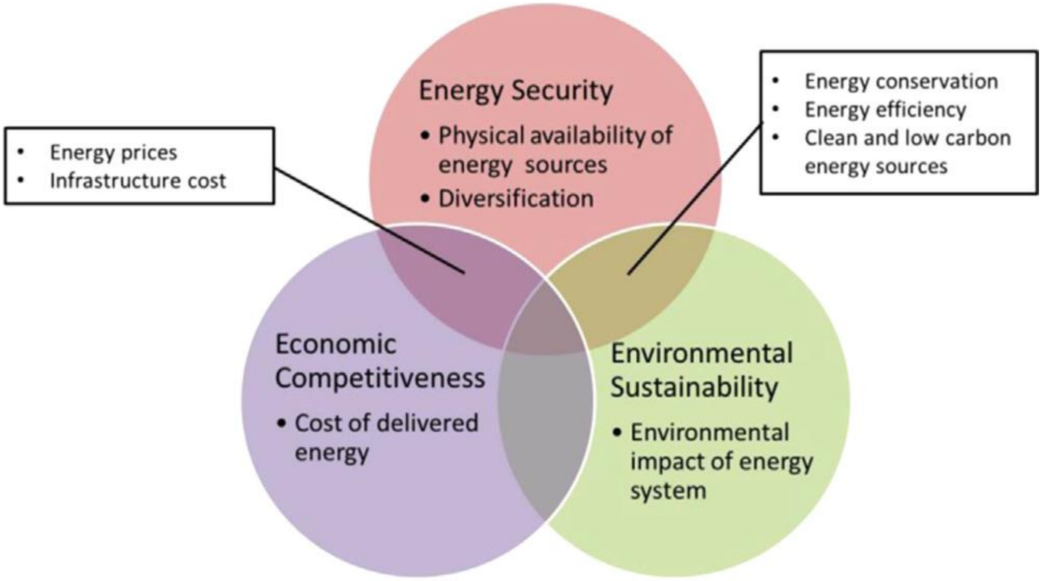

Figure 1: Energy security and the energy trilemma (Ang et al. 2015)

According to Chester (2010), the definitions of energy security have a market-centric approach as they focus on “economic issues related to the behavior of market”. This market-centric approach occurs as an effect of the “liberalisation of energy markets” and as a result, energy security “is a market outcome” defined by “the operation of the market” and described in terms of the market, with price and supply-referring to the physical availability of energy (Chester 2010). Chester (2010) also states that, security of supply risk concerns an energy supply deficit either a relative scarcity as a discrepancy between supply and demand provoking price rises, or an incomplete or total interruption of energy supplies. As a result, energy security strategies intend to confront circumstances when energy markets do not appropriately operate, and their goal should be mainly to “make markets work” (Chester 2010). Chester (2010) holds the view that “competitive markets and independent regulation” are considered the “most effective way of delivering secure and reliable energy supplies”.

Through this market-centric definition, threats to security of supply are divided into short-term risks or operational and long-term risks, concerning adequacy and hazards to supply interruption derived from sources of energy supply, storage, transition and distribution (Chester 2010).

So, the quantification of these threats became inevitable. Chester (2010) mentions plenty of quantitative indicators of energy security covering a broad range of issues from supply and demand to market signals, market response and forecasts, along with energy sources diversity, political stability, imports reliance, reliability and generation capacity. Crisis Capability Index, Supply/Demand Index and Shannon-Wiener Index are some of those indicators (Chester 2010). Hence, there are also broader definitions of energy security, comprising dimensions apart from market price and market supply, such as physical, social and environmental.

2.2.3 Dimensions and components of energy security

Several dimensions, for instance, technical, economic, political, geological, environmental and social constitute energy security. Each dimension consists of components and each component can be computed by metrics, quantitative or qualitative indicators (Paravantis & Kontoulis 2020). Asia Pacific Energy Research Centre (APERC) defines energy security, as mentioned above in Table 1, with four As: 1) availability of the supply of energy resources; 2) affordability of prices of energy resources, 3) accessibility to all; and 4) acceptability from a sustainability point of view (Paravantis & Kontoulis 2020). Cherp & Jewell (2014) point out the notable resemblance to the ‘5As’ of access to health care (‘availability, accessibility, accommodation, affordability and acceptability’). The first two As, availability and affordability, compose the classic approach to energy security as it is expressed in the twentieth century. The recent two As, accessibility and acceptability, reveal the current environmental considerations, including climate change and sociopolitical concerns like fuel poverty (Paravantis & Kontoulis 2020). The word availability indicates ‘stable and uninterrupted supply of energy’, though according to Paravantis & Kontoulis (2020), several authors adopt the term reliability in order to mention the role of energy infrastructure and the production of electricity. Regarding accessibility, it has dominated in energy security debates into the twenty-first century (Paravantis & Kontoulis 2020).

Sovacool & Rafey (2010) state four dimensions of energy security: ‘availability’, ‘affordability’, ‘development and efficiency’ and ‘social and environmental stewardship’. While Sovacool & Brown (2010) developed an Energy Security Index comprised of 10 indicators and metrics linked to four dimensions of energy security that are: “availability”, “affordability”, “energy and economic efficiency” and “environmental stewardship” as it is illustrated in Table 2.

Table 2: Defining and measuring energy security (Sovacool & Brown 2010)

Criteria	**Underlying values**	**Explanation of criterion**	**Indicators of energy security**
Availability	Independence, diversification, reliability	Diversifying the fuels used to provide energy services as well as the location of facilities using those fuels, promoting energy systems that can recover quickly from attack or disruption, and minimizing dependency on foreign suppliers	Oil import dependency, natural gas import dependency, dependence on petroleum transport fuels
Affordability	Equity	Providing energy services that are affordable for consumers and minimizing price volatility	Retail electricity prices, retail gasoline/petrol prices
Energy and economic efficiency	Innovation, resource custodianship, minimization of waste	Improving the performance of energy equipment and altering consumer attitudes	Energy intensity, per capita electricity use, on-road fuel intensity of passenger vehicles
Environmental stewardship	Sustainability	Protecting the natural environment and future generations	SO_2 and CO_2 emissions

Sovacool & Brown (2010) also mention the term ‘conflicts’ among components of energy security - competing dimensions- underlining the importance of fulfillment of all four criteria (availability, affordability, efficiency, and environmental stewardship) comprehensively. In other words, a holistic approach is required. For instance, availability and affordability, as the most predominant dimensions, often contradict one another (Ren & Sovacool 2014). Moreover, according to Ren & Sovacool (2014), renewable energy resources optimize ‘availability’ though they may also reduce ‘affordability’. According to Toke & Vezirgiannidou (2013), affordability clashes with sustainability. Mansson et al. (2014) propose the combination of different methodologies for quantitative evaluations of security of supply since there are often conflicting assumptions and opposite the promotion of solutions during the enhancement of energy security. Examples of these conflicts, according to Mansson et al. (2014), are the reduction of imports and the increase of interdependence, the reduction of threats and the increase of resilience.

Sovacool & Mukherjee (2011) propose five main dimensions of energy security: "availability", "affordability", "technology development", "environment sustainability" and "governance and regulation" which are divided into 20 different dimensions corresponding to 52 complex indicators. In the following Table 3, the dimensions, values and components of energy security are cited according to Sovacool & Mukherjee (2011).

Table 3: Energy security dimensions, values and components (Sovacool& Mukherjee 2011)

Dimension	Explanation	Underlying Values	Components
Availability	Having sufficient supplies of energy. Being energy independent. Promoting a diversified collection of different energy technologies. Harnessing domestically available fuels and energy resources. Ensuring prudent reserve to production ratios	Self sufficiency, resource availability, security of supply, independence, imports, variety, balance, disparity	Security of Supply and Production Dependency Diversification
Affordability	Producing energy services at the lowest cost, having predictable prices for energy fuels and services, and enabling equitable access to energy services	Cost, stability, predictability, equity, justice, reducing energy poverty	Price Stability Access and Equity Decentralization Affordability
Technology Development and Efficiency	Capacity to adapt and respond to challenges from disruptions, researching and developing new and innovative energy technologies, making proper investments in infrastructure and maintenance. Delivering high quality and reliable energy services.	Investment, employment, technology development and diffusion, energy efficiency, stockholding, safety and quality	Research Safety and Reliability Resilience Efficiency and Energy Intensity Investment and Employment
Environmental and Social Sustainability	Minimizing deforestation and land degradation, possessing sufficient quantity and suitable quality of water, minimizing ambient and indoor pollution, mitigating GHG emissions associated with climate change, adapting to climate change.	Stewardship, aesthetics, natural habitat conservation, water quality and availability, human health, climate change mitigation, climate change adaptation.	Land Use Water Climate Change Pollution
Regulation and Governance	Having stable, transparent, and participatory modes of energy policymaking, competitive markets, promoting trade of energy technology and fuels, enhancing social and community knowledge about education and energy issues.	Transparency, accountability, legitimacy, integrity, stability, resource curse, geopolitics, free trade, competition, profitability, interconnectedness, security of demand, exports	Governance Trade and Regional Interconnectivity Competition and markets Knowledge and Access to Information

In addition, Ren & Sovacool (2014) define energy security as "equitably providing available, affordable, reliable, efficient, environmentally benign, proactively governed and socially acceptable energy services” proposing four energy dimensions-availability, affordability, acceptability and accessibility- and 24 metrics. As mentioned by Ren & Sovacool (2014), availability involves the physical or geological existence of energy resources and the ability of a country to secure them. Affordability comprises of certain economic concerns, including price, price stability, externalities and equity. Acceptability denotes social and environmental issues regarding energy production and use. Accessibility includes geopolitics and the robustness or resilience of the entire system. According to Ren & Sovacool (2014), the four “As” of energy security are not of equal significance. They also point out that availability and affordability are more prominent and predominant in affecting other components of energy security than the dimensions of acceptability and accessibility, emphasizing the importance of harmonious evolution of the four dimensions as interconnected and not as independent.

Yao & Chang (2014) distinguish energy security indicators as simple, such as energy intensity, energy price volatility and aggregate indicators, such as energy diversity and they present energy security regarding the following four dimensions: availability of energy resources, applicability of technology, acceptability by society and affordability of energy resources.

Martchamadol & Kumar (2013) present a holistic indicator ‘‘Aggregated Energy Security Performance Indicator (AESPI)’’ developed by examining 25 individual indicators corresponding to social, economic and environmental dimensions during the evaluation of a country’s energy security.

Gasser (2020) analyzes 63 energy security indices of countries and he states that there is a significant lack of transparency in the different index construction steps. However, considerable improvement has been noticed in building energy security indices, to a certain degree due to the increasing concern of the importance of securing a reliable energy supply. Radovanović et al. (2016) claim that measuring accurately energy security is almost impossible and they proposed Energy Security Index as a new indicator that includes environmental and social aspects.

Kisel et al. (2016) makes a distinction between short-term and long-term energy security by presenting the Energy Security Matrix and energy security indicators. Short-term energy security is evaluated by the “Operational Resilience” of the energy system while long-term energy security according to Kisel et al. (2016), is distinguished by “Technical Resilience and Vulnerability, Economic Dependency and Political Affectability”. Overall, as mentioned by Kisel et al. (2016), there are four levels to energy security:

1. Operational Resilience refers to short-term energy security, meaning the capability of the infrastructure of an energy system to confront various disruptions of energy supply and demand in a

short-term period from seconds to days. Operational resilience describes mostly technical infrastructure and the result of its operations such as the situation on the market, unanticipated loss of supply and weather effects, without including the competencies of the infrastructure namely network structure, the effect of intermittent production, interconnections, the abilities of various production facilities, and stocks. In addition, operational resilience does not evaluate consequences of various possible threats to infrastructure such as terrorism, cyber threats, and water restrictions.

2. Technical Vulnerability defines the ability of an energy system to operate for a long-term period of more than 10 years. It also describes the diversity and the ability of an energy system to handle anticipated long-term loads. The age of infrastructure and its ability to promote demand side energy efficiency, diversity of supplies, the possible share of local resources, the prospective effect of malfunctions of infrastructures, matters of demand changes and probable market abuse are indicators of energy security especially for energy importing countries.
3. Economic Dependency defines the dependence of a country's economy on the energy sector, described by macro-economic indicators such as Energy Import Dependence, a portion of energy exports/imports merchandise volumes in the Gross Domestic Product (GDP) and portion of production from domestically available energy sources. Therefore, the decrease in economic and political reliance is crucial for energy importing countries, while revenue and geopolitical influence are more significant for energy exporting countries.
4. Political Affectability describes the political and geopolitical influence of other countries on the energy policy of a country. Political affectability is difficult to be measured. It significantly affects the development of the energy sector in terms of geopolitical interest, political corruption and instability of governments. There are plenty of non-measurable indications, though political stability and corruption are the main equivalent indicators for political affectability. There are various corruption and political stability indexes with uncertain predictions (Kisel et al. 2016).

In brief, Kisel et al. (2016) distinguish operational and technical resilience indicators of potential threats to an existing system, though long-term indicators pointing out the requirements not only for energy security investments but also for required regulatory modifications as a way of promoting the amelioration in future energy-mix (Kisel et al. 2016). Technical resilience indicators demonstrate the alertness of the system to handle extreme demand (Kisel et al. 2016). This awareness of the energy system is notably significant for peak consumption, as energy cannot be stored and it needs to be produced as much as it is required at the moment (Kisel et al. 2016). However, Kisel et al. (2016) mention that these indicators should be updated in the future, as technological progress reevaluates electricity and heat storage systems. The diversity of energy supply and energy suppliers regarding not only supply sources but also supply routes can be an answer to technical vulnerability issues of an energy system (Kisel et al. 2016). While a "neutral balance" according to Kisel et al. (2016), between energy export incomes and energy import expenditure must be the goal for a country as a way to reduce the effect of energy on political stability.

According to Matsumoto et al. (2017), dimensions of energy security concentrate on the categories that follow:

- Energy availability: defined by diversification and geopolitical components, containing imports, technology, energy mix, geographical region and transport roads.
- Infrastructure: essential component in providing firm and uninterrupted energy supply, including installations of energy transmutation, distribution and transmission.
- Energy prices: delineated by the affordability of energy supply, the competitiveness of energy markets, the absolute price level and price volatility.
- Societal effect: defined by the correlation of energy and society including acceptability and energy poverty.
- Environment: environmental concerns and sustainability are strongly correlated to energy due to pollution, carbon emissions and further environmental matters during power plants operation along with renewable energy.
- Governance: conscientious and competent (good) governance protects against short-term energy disturbance, and foresighted governments attempt to guarantee long-term energy security via diplomacy, the government's part in policymaking, gathering information and regulatory procedure.
- Energy efficiency: strongly correlated to energy intensity, measurements, practices, improved technologies and systems in order to reduce energy demand, hence enhancing energy security (Matsumoto et al. 2017). Energy Intensity, according to the U.S. Department of Energy, is calculated by the amount of energy demanded per unit output or activity, so that the use of less energy to produce a product decreases the intensity.

Matsumoto et al. (2017) also mention that energy availability is the most significant component in the evaluation of countries' energy security, since it is encompassed as an indicator in 99% of relevant studies, even though indicators for energy dimensions differ among research based on diverse concerns in energy security's aspects.

Azzuni & Breyer (2017; 2018) pose a depiction of energy security consisting of 15 dimensions and plenty of parameters for each dimension as it is depicted in Figure 2.

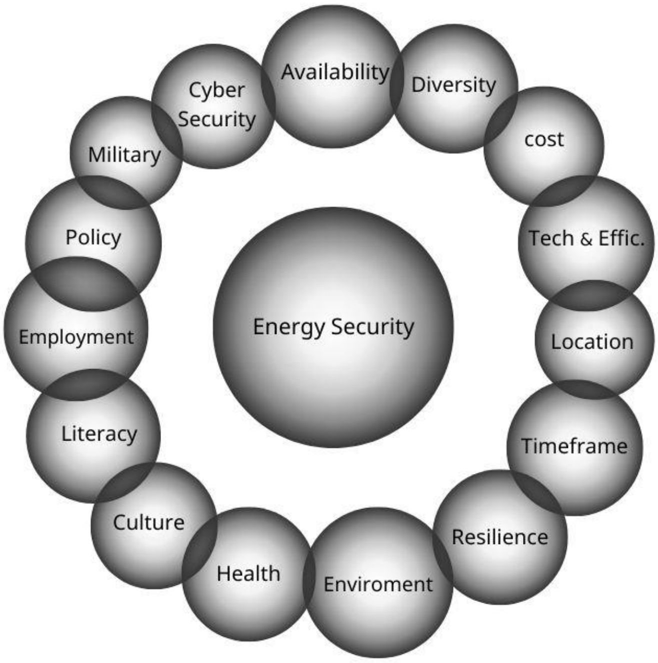

Figure 2: Energy security dimensions (Azzuni & Breyer 2018)

In fact, Azzuni & Breyer (2017) present the following dimensions:

- Availability: including the availability of energy resources, availability of transforming resources into services-with energy infrastructure- and availability of energy consumers as the notion of the access to energy services for customers.
- Diversity: including diversity of fuels- energy carriers-, diversity of sources, diversity of making energy available to end-users including technologies and transmission, and diversity of consumers-the consumers' profiles. In essence, more diverse systems are more secure.
- Cost: expressed otherwise as the affordability of energy services or the price to be paid for energy distinguished by the following parameters. The first is energy price examining the stability of energy prices, price volatility, peak oil, pricing system and energy poverty. The second is the cost of energy security regarding supply disruption and the third parameter is the cost of securing the system taking into account the infrastructure cost, the cost of environmental repercussions, healthcare, educating people, the military cost protecting the energy sources and the social cost as to welfare.
- Technology and Efficiency: New technologies can provide solutions for the production, transit, storage, conversion, and distribution of energy, improving energy security. Energy efficiency

has a meaningful role in fulfilling energy security. So, is the second parameter for this dimension, while energy intensity is the third one and energy conservation follows as a term that describes the measures in energy demand reduction.

- Location with its parameters: energy system boundaries, the location of energy source, the density factor-centralized/decentralized-, the land use, globalization, the human settlement and population distribution, the location's geography and the industrial intensity.
- Timeframe: The first parameter is the timeline regarding the current energy system. The second one is the length of the event, long term or short term. Long-term increasing prices impact the economy in a different way than an unexpected, price increase. The third parameter is the length of the effect, for instance the effect of the establishment of IEA as a result of the Arab oil embargo in 1973.
- Resilience: the adaptive capacity to function after disturbance. A resilient energy system can shift diverse energy suppliers, diverse energy carriers and energy transition routes and diverse consumers.
- Environment: including exploitation rate and energy resources' location, extraction methods and the outcome of the energy usage, the effect of climate change and the interconnection between water and energy (energy-water nexus).
- Health: impact of people's health on the energy system, the impact of the energy system on the health of energy sector workers, consumers and international society.
- Culture: how cultures impact energy security otherwise mentioned as social acceptability, including cultural effect, cultural acceptance of laws for example CO_2 tax and cultural aspects formed by energy conditions.
- Literacy: Information availability (public awareness, market information, educational program)
- Employment: impact of energy security on the unemployment rate and the impact of employment rate on energy security.
- Policy: the correlation between energy security and the political system, its stability, its regulations and its internal and external relations. Political uncertainty and corruption are threats to energy security.
- Military: the use of energy for military intents, the concept of 'militarization', the implication of military forces to impact energy security through energy resources in order to achieve political objectives, the usage of energy as a political weapon and the destabilization factor (resources curse, environmental degradation, 'economies of violence') consist of the parameters of this dimension.

- Cyber Security: all energy infrastructures are based on digital support. Consequently, the damage to cyber security can lead to considerable economic loss. Connectivity, software such as SCADA and ICS and IT skills are the parameters of cyber security.

According to Azzuni & Breyer (2017) availability, cost, and policy are the basic dimensions of energy security in the literature. Although cyber security has the least references, comprises one of the most significant dimensions of energy security nowadays (Azzuni & Breyer 2017).

At last, Ayoo (2020) presents the following energy security indicators: energy reserves, energy production and consumption, energy trade balances, energy prices, energy diversity and share of renewable energy.

2.3 Energy security and renewable energy

Renewable energy functions, as mentioned above, as an energy security indicator. Therefore, in this section, the increasing interest in renewable energy and energy transition are presented, followed by the examination of the contribution of renewable energy sources to energy security along with their impediments.

2.3.1 The increasing interest in renewable energy and energy transition

As noted in the historical background of energy security, global geopolitics could threaten energy security. Renewable energy is estimated as a game changer in energy security; consumer countries have become producers; producer countries have become consumers; and transit countries have changed to new players (Paravantis & Kontoulis 2020). Thus, the global energy scenery, according to Paravantis & Kontoulis (2020), lies in the "middle of a game-changing revolution in source rock resources".

The common new aspect in all energy security notions, as mentioned by Proskuryakova (2018), should be the concern of new energy sources, renewables. Their use patterns, production and transportation completely vary from those of fossil fuels (Proskuryakova 2018). So, as claimed by Proskuryakova (2018), countries will concentrate more on the transmission of power, enhancing speed and efficiency rather than the transportation of fossil fuels by tankers and pipelines. Hence, compared to hydrocarbons a more equivalent allocation of renewables worldwide will alter the concept of 'resource rich' and 'resource poor' countries (Proskuryakova 2018).

Renewable energy technologies comprise solar photovoltaic and thermal systems, wind, biomass, hydroelectric power, ocean thermal, tidal and geothermal (Mathews 2014). According to Olz et al. (2007), the definition of renewable energy sources encompasses energy generated from solar, wind, biomass, the renewable fraction of municipal waste, geothermal sources, hydropower, ocean, tidal and wave resources, and biofuels.

Lu et al. (2020) state that facing the increasing energy demand and the reduction of the environmental impact are the two "intertwined issues" confronted in the 21st century. Moreover, Gozgor et al. (2020) predict a steady rise in the demand for renewable energy in the 2020s inspired by the growing climate change awareness and issues of energy security and energy poverty. The authors also point out that an upper level of economic globalization fosters renewable energy. Adams & Nsiah (2019) state that economic growth advances to environmental degradation whereas, urbanization has an adverse effect on carbon dioxide emissions. Ibrahiem & Hanafy (2021) also mention that economic growth, foreign direct investment, trade openness and emissions of carbon dioxide trigger renewable energy.

Global warming or the greenhouse effect according to Speight (2019), is an environmental problem that copes with the possibility of global climate change caused by raised levels of atmospheric ‘greenhouse gases’. There exist particular gases in our atmosphere regulating the heat that is kept close to the surface of the Earth (Speight 2019). Scientists, as mentioned by Speight (2019), speculate that a rise in these greenhouse gases will lead to raised temperatures globally causing many calamitous environmental impacts. Empiric evidence indicates that global climate change is occurring at an alarming rate due to the release of CO_2 (carbon dioxide) emissions into the atmosphere (Mathews 2014). Mathews (2014) claims that approximately 85% of the contemporary global energy production and use is founded on or derived from fossil fuels. Moreover, Jaforullah & King (2015) state that the amount of CO_2 emissions which mainly proceed from combustion of fossil fuels, is estimated at 87% of the global energy supply in 2012. So, according to Lu et al. (2020), energy use can trigger crucial environmental pollution.

The gaseous emissions from power plants, as mentioned by Sayed et al. (2020) consist of two groups: Greenhouse gases (GHGs) and aerosols. The GHGs comprise carbon oxides COx (CO and CO_2), sulfur oxides SOx (SO_2 and SO_3), nitrogen oxides NOx (N_2O, NO, and NO_2), and volatile organic compounds (VOCs). The aerosols consist of particulate matter (PM) and other aerosols (Sayed et al. 2020). According to Sayed et al. (2020), the majority of global GHGs emissions come from heat and power 42%, transportation 25% and industry 19% while, coal is accountable for 72.5% of the global CO_2-eq emissions, although it contributes only 31.8% of the global power supply.

The immoderate blazing of fossil fuels in the already reduced natural resources and causes a constant raise of carbon dioxide (CO_2) emissions, which is considered to be responsible for the rising average of global temperatures (Lu et al. 2020). Bekun et al. (2019) state that anthropogenic CO_2 emissions capture heat in the atmosphere, which means rising the global temperature. Stanek et al. (2016) also mention that electricity generation in power plants based on fossil fuel is intertwined with the discard of hazardous wastes such as greenhouse gases. While energy related carbon dioxide (CO_2) emissions constitute two-thirds of the total greenhouse gases (Gielen et al. 2019). Each kWh of electricity generated from coal releases 1 kg of CO_2 into the atmosphere (Mathews 2014). Mathews (2014) also claims that global greenhouse gas emissions have increased by 70% between 1970 and 2004, and by another 8% since 2011. Furthermore, CO_2 emissions have increased by about

110% during this period representing 77% of the anthropogenic emissions in 2004 (Mathews 2014). Thus, as Valentine (2011) states, humanity confronts an environmental constraint on the fossil fuel energy increase.

The first attempt to notify of the increasing threat of climate change to environmental, social and economic welfare, took place at the World Climate Conference in 1979 where governments were summoned to 'foresee and prevent potential man-made changes in climate' (Can Şener et al. 2017). A few decades later in 1997, the first international treaty, the Kyoto Protocol defined the binding targets in order to reduce greenhouse gas emissions for the adopted countries (Can Şener et al. 2017; Paravantis et al. 2019). According to Can Şener et al. (2017), the Kyoto Protocol is regarded as a 'historic milestone' in the fight against increasing greenhouse gas emissions and global warming.

In 2014 in Copenhagen, the Intergovernmental Panel on Climate Change (IPCC) and the leaders of the United Nations (UN) raised their concerns about the principal outcomes of the IPCC Fifth Assessment Synthesis Report (IPCC, 2014) and the immediate future (Lu et al. 2020). According to Lu et al. (2020), the UN Secretary-General stated: 'Leaders must act, time is not on our side' underlining the imperative need for governments' actions to confront environmental matters and energy crisis issues. Actually, the Paris Agreement in 2015 which the United States and China agreed to obey, as mentioned by Lu et al. (2020), comprises the promising reaction of the world's governments in this predicament.

In 2015, the United Nations General Assembly (UNGA) adopted the Sustainable Development Goals (SDGs), providing a substantial framework for international cooperation in order to achieve a sustainable global future (Gielen et al. 2019). In brief, as mentioned by Gielen et al. (2019), the 17 SDGs and their 169 targets, at the core of 'Agenda 2030', encompass the elimination of extreme poverty, the battle against inequality and injustice, and the protection of the environment. Sustainable energy is significant in Agenda 2030 as the global objective on energy SDG 7 includes, according to Gielen et al. (2019), the following targets: secure affordable, reliable and universal access to contemporary energy services; enhance the share of renewable energy in the global energy mixture substantially; and multiply by two the global rate of amelioration in energy efficiency. As mentioned by Omri & Belaïd (2021), environmental degradation and socio-economic growth are among others the keys to reaching the SDGs. The role of renewable energy in rebalancing these goals is turning to a considerable subject of some debates in the current literature (Omri & Belaïd 2021).

Gökgöz & Güvercin (2018) mention that the European Union policies are also promoting renewable energy and energy efficiency among the member countries due to its high dependency on energy imports and the enormous gap between energy consumption and production capacity. Olz et al. (2007), also point out that the explanation for the increasing share of renewable energy supply in the European energy mix is the evolution of strong interconnection within the European Union member states and its neighboring states, comprising Middle Eastern and North African countries.

In December 2018 the European Union approved a recast of the Renewable Energy Directive, which institutes the new target of 32 percent renewable energy to be fulfilled by 2030 (Monti & Martinez Romera 2020). In other words, Member States are conjointly compelled to guarantee that the share of energy originating from renewable sources in the European Union's gross final consumption of energy in 2030 will be at a minimum of 32 percent (Monti & Martinez Romera 2020). The boost and the support of renewable forms of energy constitute an essential goal of EU energy and climate policy (Monti & Martinez Romera 2020). Hence, the legislation of the European Union multiplies the benefits of the implementation of renewable energy sources, functioning as an attempt that provides environmental security and sustainable development, along with the improvement of energy security, technological progress and local employment (Monti & Martinez Romera 2020).

Valdés Lucas et al. (2016) state that the implementation of renewable energy sources is an outcome of a combination of energy security strategies comprising environmental issues instead of being entirely triggered by energy policies toward sustainability. They also claim that among energy security strategies, diversification of energy sources via renewable energy implementation is a more consistent strategy compared with the pursuit of energy independence relying on renewable energy sources.

Energy efficiency and renewables provide an affordable, reliable and safe way to fulfill decarbonization (Paravantis & Kontoulis 2020). Can Şener et al. (2017) mention renewable energy sources as tools to diminish CO_2 emissions and therefore lessen climate change. Fossil fuels are finite resources (Valentine 2011; Mathews 2014) and are considered the major contributor to the rise in anthropogenic greenhouse gas concentrations (Can Şener et al. 2017). On the contrary, renewable energy sources "cannot be depleted" releasing at their use, a small portion or no further CO_2 emissions (Can Şener et al. 2017). As previously mentioned, a transition from fossil fuels to low-carbon renewable energy is already a necessity. Climate change and regional air pollution are the determining factors for energy transition worldwide (Gielen et al. 2019).

The concept of energy transition as mentioned by Hache (2018) is to the same extent vague pointing to a less complicated definition of energy transition as “the progressive replacement of the main primary source of energy consumption”. According to Lu et al. (2020) in human evolution, three ordinary energy transitions have already occurred. Firstly, coal substitute wood as the main energy source; then, oil substitute coal becoming the dominant energy source; lastly, the transition from fossil fuels to renewable energy (Lu et. al. 2020). Hache (2018) states that in the United States, it took more than thirty-five years for coal to substitute wood in the energy mix in 1885 and almost a century for oil to turn into the main consumed energy source in 1950. Lu et al. (2020) point out that under the prism of climate change effect, the energy transition from fossil fuel to renewable energy sources, is one of the major challenges that governments confront worldwide. Omri & Belaïd (2021) claim that accomplishing sustainable energy is possible to promote energy transition with low-carbon sources, move to a healthier and cleaner environment, enlarge access to electricity, and therefore increase investment in renewable energy technology. Hence, as mentioned by Omri & Belaïd (2021), there is a general opinion that green energies are anticipated to have a more fundamental role in future energy systems.

Gielen et al. (2019) mention the importance of technological innovation in the energy transition particularly via renewable energy underlining also the significant “synergy” of energy efficiency and renewable technologies in the energy transition. Renewable energy sources can supply two-thirds of the total global energy demand meanwhile contributing to the decline of greenhouse gas emissions at considerable amounts that are required in order to restrict the average global surface temperature increase below 2 °C (Gielen et al. 2019). Osman et al. (2022) also claim that renewable energy sources “decarbonize” 90% of the electricity industry by 2050 limiting global temperature rise to 1.5 °C.

Moreover, the costs of renewable energy technologies which have been dramatically reduced, make renewables more ‘attractive’ all over the world, notably in low and middle-income countries, where most of the future energy demand will rise (Osman et al. 2022). Except for geothermal and hydropower-derived energy, as mentioned by Osman et al. (2022), renewable energy technology costs have considerably reduced since 2010 (Osman et al. 2022). Only the cost of solar energy was reduced by 88% between 2010 and 2021 while the cost of solar and wind-generated electricity per kilowatt-hour in 2021 was four to six times below the cost of fossil fuels in 2022 in Europe (Osman et al. 2022).

Even though, energy transition and geopolitics of renewable energies are considered ‘softer’ and less ‘conflictual’ than carbonated energy resources, the diffusion of renewable energies leads indisputably to more complex global energy geopolitics (Hache 2018). Energy transition brings new challenges and potential shifts in interstate relations by affecting countries producing fossil resources (Hache 2018). The diminution of the import amount of fossil energy resources would impact producing countries' security of demand and would have a huge macroeconomic effect on export and budgetary revenues, modifying the national and regional balance and as a result affecting also the economic and international financing networks (Hache 2018).

The widespread diffusion of renewable energies in the global energy mix may induce new dependencies (Hache 2018). According to Hache (2018), the reliance on fossil energy resources could be substituted for reliance on other resources, including strategic metals, a major technological component for the dissemination of the most efficient decarbonization technologies in countries in the global South. These raw materials are extremely important in the development of energy transition technologies and, according to Hache (2018), these raw materials include rare metals, rare earth metals, battery components metals such as cobalt and lithium, traditional non-ferrous market components including copper, tin, nickel and more industrialized market components such as cement and steel but also water. Plenty of raw materials are crucial in decarbonisation technologies, distribution and the energy production and as a result, they could become the leading factors of technologies prices contributing to the limitation or to the expansion of different technologies (Hache 2018). Hence, investment in renewable energy research and development generates a lot of geopolitical issues concerning the localization of renewable energy innovation and the presence of a new "market power" for different countries, companies or groups of countries (Hache 2018). New, unexpected interdependencies including reliance on crucial materials, new geopolitics of patents and the implementation of renewable diplomacy emerge during the energy transition (Hache 2018).

2.3.2 The contribution of renewables to energy security

Renewable energy systems can ameliorate some aspects of security however, they will not necessarily resolve all types of security issues and new issues will occur (Johansson b, 2013). Olz et al. (2007) mention that renewable energy systems are "diverse", "widely available" and occasionally at a competitive cost. Johansson (2013, b) states that the main profit of renewable energy is that it relies on flows rather than "exhaustible stocks". Furthermore, Nie & Yang (2016) point out that the use of renewable energy diminishes the consumption of conventional energy and enhances energy security. Valdés Lucas et al. (2016) also mention that renewables are capable of enhancing energy security. While Ang et al. (2015) claim that renewable energy sources are usually more sustainable than conventional ones.

According to Aslantürk & Kıprızlı (2020), there is a positive interconnection between sustainable economic growth, assuring energy security of supply and the usage of renewable energy resources. Omri & Belaïd (2021) also claim that renewable energy sources contribute to the reduction of adverse effects of the indicators of CO_2 emissions on human development and economic growth. Ibrahiem & Hanafy (2021) mention that economic progress prompts countries to alter to renewable energy in order to achieve "qualitative economic growth" and sustainable development. The principal incentives of renewable energy sources, as stated by Ibrahiem & Hanafy (2021), are the reduction of carbon dioxide emissions, the decrease of energy use, the trade liberalisation, the increase of attractiveness of foreign direct investment, the improved energy security and the rise of population. Omri & Belaïd (2021) hold the view that renewable energy has a substantial potential to stabilize the environmental, social, and economic objectives. Hence, renewable energy, according to Omri & Belaïd (2021), is considered a remarkably affected investment opportunity from an economic and social perspective.

2.3.2.1 Improving the 4 As of energy security

In this paragraph the contribution of renewables to energy security is explained through the categorization into the 4 dimensions of energy security according to Ren & Sovacool (2014). More precisely, Ren & Sovacool (2014) propose the following metrics in each dimension:

- Availability: security of supply, self-sufficiency, diversification, renewable energy, technological maturity.
- Affordability: price stability, dependence, market liquidity, decentralization, electrification, equity.
- Acceptability: environment, social satisfaction, national governance, international governance, transparency, efficiency, innovation, investment and employment.
- Accessibility: import stability, trade, political stability, military power, safety and reliability.

Enhancing availability

Global dependency on fossil fuels as a main source of energy threatens energy security worldwide (Novikau 2021). According to Valentine (2011), the most secure mean to reduce energy supply risk is to increase domestically manageable energy supplies, such as an electricity regime dominated by solar power, wind power and hydropower. All these forms of energy provide high levels of domestic control of a country over the energy supply chain (Valentine 2011). Renewable energy, contrary to fossil fuels, is “abundant, inexhaustible and generally accessible” without geographical restrictions (Aslantürk & Kıprızlı 2020), and according to Johansson (2013 b), their geographical location is even less condensed.

Regarding coal reserves, the global coal reserves come to $7.9 \cdot 10^6$ TWh, the oil reserves are equal to $2.1 \cdot 10^6$ TWh and the gas reserves comprise $1.9 \cdot 10^6$ TWh (Azzuni & Breyer 2017). According to Azzuni & Breyer (2017), oil reserves are adequate for more than 55 years, 52 years of recent production considering the current global energy consumption, or for 23 years in case global consumption increases by 5 per year. In addition, the global proven reserves of coal are assessed to be sufficient for 122 years of production at recent paces; verified reserves of natural gas are assessed to maintain current production levels for 61 years (Azzuni & Breyer 2017). Renewable energy or ambient energy according to Azzuni & Breyer (2017), as solar energy, wind power, flow-of-the-river, and marine energy can cover the energy demand. For instance, the theoretical capability of solar energy only is 89.300 TW which is about 7.000 times the global energy consumption in 2013 which was 162 TW (Azzuni & Breyer 2017). Hence, energy is abundant and sufficient to meet global demand (Azzuni & Breyer 2017). Therefore, Azzuni & Breyer (2017) state that there are no issues of energy security in terms of availability of the energy sources worldwide.

Nevertheless, the energy resources, mostly fossil fuels and the energy demand are not scattered equally worldwide (Azzuni & Breyer 2017). So, renewable energy sources can contribute to the balance between the existing resources and the demand (Azzuni & Breyer 2017). Moreover, according to Azzuni & Breyer (2017) the depletion of energy sources comprises a threat to energy security, underlying the thought that the implementation of renewables occurs due to economic reasons rather than fossil fuel depletion.

Gielen et al. (2019) state that renewables such as wind, solar PV (photovoltaic), solar thermal and modern bioenergy provide on the supply side. As energy efficiency mitigates demand growth thereby it delivers about one quarter to the total growth of renewables share in overall final energy consumption (Gielen et al. 2019). Meanwhile as mentioned by Gielen et al. (2019), 20 - 44% of the energy intensity enhancement can be ascribed to the increase of renewable energy underlying the significant synergy among wider energy efficiency and larger shares of renewable energy.

Aslantürk & Kıprızlı (2020) state that renewable energy resources provide long-term energy supply security by contributing to energy supply diversity, reducing the dependence on external sources and increasing energy efficiency. The implementation of renewable energy systems in electricity generation, as mentioned by Olz et al. (2007), decreases both the price and volume which are physically available components of the energy security index and therefore, they ameliorate energy security. Olz et al. (2007) also claim that renewable energy resources diminish the risk of energy supply interruptions by contributing to fuel mix diversification and providing different options for generating electricity, producing heat and transport fuels. Moreover, Sovacool (2009) states that renewable energy sources improve national energy system security decreasing the risks of terrorist attacks, natural catastrophes and the reliance on supply from hostile and unsteady regions. Olz et al. (2007) also mention that the rise of renewables' share in the energy mix can lead to a reduction in the impacts of supply variations and disruptions. They also state that renewable electricity systems can provide security against sabotage, terror, and localised natural disasters, due to their scattered deployment.

According to Johansson (2013, b) security of supply relies not only on balances between supply and demand but also on unforeseen disturbances, technical malfunctions and hostile attacks. So, transportation routes and technical malfunctions characteristics are factors of the risk disturbances though, market structures and supervising strategies determine the system's vulnerability (Johansson, 2013 b). The implementation of renewables as claimed by Johansson (2013, b), mitigates these risks of energy supply.

Aslantürk & Kıprızlı (2020) state that diversification of supply and the existence of competitive energy markets is the approach to defend the economic order against supply disruption. In this regard, having one market is less secure than having more (Azzuni & Breyer 2017). Moreover, the reliance on a single local supplier, as mentioned by Johansson (2013 b), might be as sensitive as the reliance on a broader regional or global market. Tsoutsos et al. (2005) claim that renewable energy systems enhance regional or national energy self-sufficiency, contribute to the diversification of supply, accelerate the development of rural electrification system in developing countries and lessen the required transmission lines of the electricity grids. According to Anwar (2016), the energy supply side exposed better diversification of energy sources through the higher shares of renewables in the primary energy supply mixture verifying energy security enhancement throughout 2005–2050.

In addition, according to Azzuni & Breyer (2017), a more diverse system that includes renewables is more secure and diminishes the jeopardy of electricity blackouts. The effect of renewables on diversity, as mentioned by Johansson (2013 b), relies on the transition phase of the system. In the beginning, when the penetration of renewables is low, diversity will rise with the increasing use of renewables, though the diversity profits might be reduced when renewables dominate the system (Johansson, 2013 b).

Enhancing affordability

Renewable resources as mentioned by Aslantürk & Kıprızlı (2020), reduce energy production costs, while the obtained return of renewable energy investments is more safely as these investments are periodic and fixed cost. So, renewable resources steady energy prices and enhance competitiveness in international markets, mitigating the effect of international energy price fluctuations on national economies (Aslantürk & Kıprızlı 2020). In other words, renewables turn economies more robust against the insecurity in global fossil fuel markets and price fluctuations (Aslantürk & Kıprızlı 2020). In addition, renewable energy sources support the sustainability of economic growth providing substantial profits in exports, reducing energy import costs and preventing foreign exchange outflows (Aslantürk & Kıprızlı 2020). Tsoutsos et al. (2005) mention that renewables also support the deregulation of energy markets.

According to Azzuni & Breyer (2017), energy price volatility has significant uncertainty. Renewable energy is the approach, as mentioned by Azzuni & Breyer (2017), for a cost-effective future energy system in cases of price augmentation caused by a reduction in production, above the inflection point where supply is less than demand. Renewables enhance energy security as a low-cost alternative in the long run with required capital expenditure and limited operational expenditures (Azzuni & Breyer 2017). Therefore, energy systems with almost zero running costs and only an upfront payment, such as renewables energy systems are considered more secure (Azzuni & Breyer 2017).

Moreover, Olz et al. (2007) state that a diverse portfolio of energy supply alternatives lessens energy security risks such as fuel price volatility caused by resource concentration and fuel cost variations affecting the risk structure of generation portfolios and improving competitiveness. Sovacool (2009) also claims that renewable energy sources are “less subject to price volatility”. Can Şener et al. (2017) mention that conventional energy sources’ volatile prices affect negatively global economies and promote research and study of sustainable energy options sheltered with more foreseeable effects on economic growth.

Johansson (2013, b) states that the significance of diversity in reducing price vulnerability depends on the price correlation between diverse energy sources on the market and the system’s vulnerability to price fluctuation. In the case of renewable sources, as mentioned by Johansson (2013, b) the sensitivity to expected energy prices might be often less distinct than in fossil fuels due to their substantial upfront costs.

According to Olz et al. (2007), the diversification of energy sources and the substitution of fossil fuel sources including natural gas with renewables, mitigate the risk of high gas prices over the short and long term as the demand for these sources reduces and therefore put downward pressure on natural gas prices. In addition, renewable energy sources as claimed by Olz et al. (2007) can reduce both transmission losses and costs in case their generation is located near the demand load of end-users. Olz et al. (2007) also state that renewables ensure a direct hedge against price volatility and against escalating natural gas prices reducing the demand for fossil fuels recourses. Exploiting the different natural cycles of diverse renewable energy technologies, renewables can decrease uncertainty and volatility, ameliorating forecasting and modeling of natural fluctuations by permitting communication among markets and grid operators and thereby, contributing also to the evolution of electricity grids and electricity markets (Olz et al. 2007).

Azzuni & Breyer (2017) also state that renewables as an inexpensive alternative in the long run, enhance the energy security of an energy system relying on the structure of the cost and the benefits. Mainly, renewables need capital expenditures with fewer operational expenditures. Therefore, as mentioned by Azzuni & Breyer (2017), an energy system with only in-advance deposits and almost zero operating cost, is regarded as more secure.

Enhancing acceptability

As already mentioned above, the implementation of renewable energy sources mitigates climate change. Johansson (2013, b) mentions that renewable energy resources incite a smaller impact regarding climate change in comparison to fossil fuels. The use of renewable energy sources, apart from biomass (Johansson, 2013 b), contributes to the decrease of the greenhouse gases emissions mostly CO_2 and NO_X while they also restrain toxic gas emissions of SO_2 and particulates (Tsoutsos et al. 2005) or sulphur, nitrogen oxides and VOCs -volatile organic compounds- as mentioned by Johansson (2013, b), by expelling zero or nearly zero percent of these pollutant gases (Omri & Belaïd, 2021). According to Saidur et al. (2011), these pollutant gases are responsible for acid rain and global warming which trigger the greenhouse gas effect, rise in the sea-level, and changing weather conditions. Jaforullah & King (2015) also point out that CO_2 emission levels are negatively correlated with the use of renewable energy.

More precisely, Saidur et al. (2011) mention that a 6kW wind energy system can save 2.5 – 5 tonnes of CO_2 while they also point out that 1GWh of wind power can save 600 tonnes of CO_2

emission. Sayed et al. (2020) also claim that 189 million metric tons of CO_2 in the power sector are saved by wind energy equal to 42 million cars' worth of CO_2 emissions only in 2019.

Moreover, Hosenuzzaman et al. (2015), state that photovoltaic (PV) systems save 0.53 kg CO_2 emission for every kWh of electricity produced. According to Hosenuzzaman et al. (2015), the use of photovoltaic systems can diminish 69-100 million tonnes of CO_2, 68,000-99,000 tonnes of NO_X and 126,000-184,000 tonnes of SO_2 before 2030.

Renewable energy sources enhance energy security by counting on national energy sources, contributing to combat global warming pollution, and protecting human health from air pollution (Omri & Belaïd, 2021). Tsoutsos et al. (2005) claim that the implementation of renewable energy sources ameliorates the quality of water resources, while Omri & Belaïd (2021) state that it mitigates air and water pollution by expelling fewer toxins. In addition, this implementation contributes to the reclamation of degraded land (Tsoutsos et al., 2005; Johansson, 2013 b) and to the maintenance of natural areas and resources (Omri & Belaïd, 2021).

According to Omri & Belaïd (2021), the use of renewables provides considerable public health benefits by refraining from neurological damage, heart attacks, cancer and breathing problems. So, renewable energy augments the health prospects and prosperity of a community by reducing the impact of CO_2 emissions and therefor, expands life prospects and decreases health costs (Omri & Belaïd, 2021). Sayed et al. (2020) mention that further gaseous emissions such as SOx, NOx, and PM (particulate matter), which induce smog cause asthma attacks and serious health effects. According to Sayed et al. (2020) only in 2018, the decrease in such pollutants saves $9.4 billion in public health, contributing to an enormous positive impact on the environmental and human health fields. Therefore, renewable energy ameliorates the quality of life of all living beings and protects them from future harm, through the enhancement of environmental quality (Omri & Belaïd 2021).

Moreover, renewable energy also contributes to other determining factors of human development beyond health such as hunger, poverty- enhancing access to food and water-, gender equality, education, job opportunities and enhancement of subsistence (Omri & Belaïd, 2021). Adams & Nsiah (2019) indicate the use of renewable energy as a substitute for fossil fuel in decreasing energy poverty while they point out renewable energy as the ‘golden thread’ to all Sustainable Development Goals since it combines growth, equity and environmental sustainability. Renewable energy resources provide substantial work opportunities (Tsoutsos et al. 2005; Valentine 2011; Stigka et al. 2014), improving the advancement of domestic industry (Valentine 2011). Saidur et al. (2011) state that wind energy systems benefit the economy in agricultural areas where they exist. Aslantürk & Kıprızlı (2020) also claim that besides the diffusion of renewable energy production networks to provincial and distant country regions, renewables can increase production sites and open new business fields. Moreover, Azzuni & Breyer (2017) mention that increased unemployment rates could be an outcome of a less secure energy system. Sovacool (2009) states that huge technological systems are at the same time social and technical, underlining the existence of social components. According to Sovacool (2009) generation, transmission and distribution of electricity transpires within a socio-technical system that ranges beyond the engineering sphere. Social institutions as regulatory bodies and financing firms, and technical artifacts are required for electricity systems' function (Sovacool, 2009).

Azzuni & Breyer (2017) mention that the utilization of renewable energy sources ameliorates energy security as it fuses better energy efficiency, superior environmental fulfillment and more favorable social effects. In other words, it combines the benefits of a centralized system with the security benefits of a decentralized system. Energy efficiency is a consequential component of energy security (Azzuni & Breyer 2017). Therefore, as mentioned by Azzuni & Breyer (2017), the objective of Research & Development is the rise of efficiency as augmenting efficiency by technological advancement, turns the energy system more secure meanwhile contributes to climate change mitigation. Efficiency is increasing the output units per one unit of input by enhancing the operation of energy equipment or changing consumer behavior (Azzuni & Breyer, 2017). According to Azzuni & Breyer (2017), consumer efficiency is the proportion of energy service to the energy needed to provide that service. As this proportion augments, raised efficiency will raise the availability of energy for other uses (Azzuni & Breyer, 2017). Olz et al. (2007) state that energy efficiency advancement via demand-side management and technological innovation is capable of cost-effective mitigation of large-scale effects of energy supply interruptions in electricity, heat, and to some extent in the transport sector too. In addition, as mentioned by Olz et al. (2007), renewable energy systems increase grid capacity and cross-border interconnections and improve the absorption of efficient demand-side response apparatus.

Enhancing accessibility

Johansson (2013 b) mentions that renewables are typically presumed domestic resources either explicitly or implicitly decreasing import reliance. Proskuryakova (2018) also claims that substituting fossil fuel imports with renewable energy generation will have an effect on the energy and trade balance structure. Olz et al. (2007) and Ang et al. (2015) also mention that renewables could reduce the requirement for energy imports and thus, contribute to import dependency.

Valentine (2011) states that renewable energy enhances resilience as decentralized technologies; lessening the risk from technological failures or terrorist attacks which could severely damage a nation’s electricity grid. Azzuni & Breyer (2017) define resilience as the ability to resist disruptions without changing the energy security baseline, as the capacity in other words, to adapt and endure disturbance continuing delivering services at the same operation and the same structure. A resilient system, according to Azzuni & Breyer (2017), can shift among various energy suppliers, various energy transition routes and energy carriers and different consumers.

Furthermore, Azzuni & Breyer (2017) mention that political instability provokes a threat to energy security underlying the strong correlation between policy and energy security. Though, the implementation of renewable energy systems, as mentioned by Olz et al. (2007), mitigates geopolitical security risks. Gielen et al. (2019) also mention that through technological improvement renewable energy resources decrease the risk of policy volatility.

2.3.2.2 Beyond the definition of 4 As

Beyond the contribution of renewable energy in dimensions of 4 As of energy security, Valdés Lucas et al. (2016) pose in Figure 3 a ‘causal taxonomy of energy risk’ where energy risks are analyzed into primary energy risks -including socioeconomic or technical drives-, secondary energy risks caused by primary energy risks- including disruption of energy supply or environmental risks and risks to human health and property, and finally exposure risks and vulnerabilities.

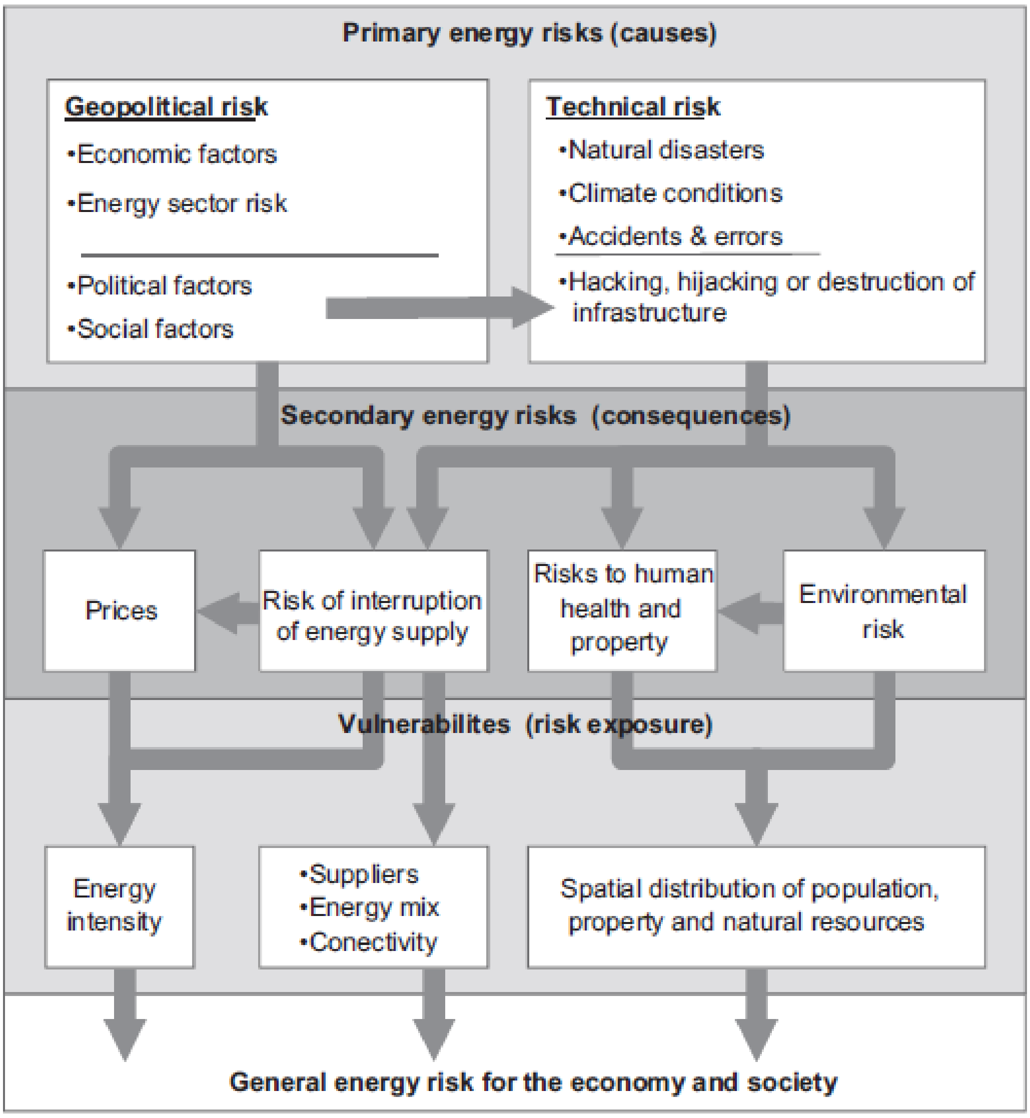

Figure 3: A causal taxonomy of energy risk (Valdés Lucas et al. 2016)

According to Valdés Lucas et al. (2016), renewable energy sources can lessen energy risks in each level of this ‘causal taxonomy’. As for primary energy risk, the decentralization of renewable energy facilities provides more security regarding physical breakdown or sabotage, than centralized conventional ones (Valdés Lucas et al. 2016). Apropos of secondary energy risks, as mentioned by Valdés Lucas et al. (2016), renewables, excluding hydropower, are significantly more secure than conventional energy sources in the event of an accident. In addition, as renewables are considered ‘zero marginal cost’ technologies they are not influenced by price volatility in the international energy market as oil, natural gas or coal are (Valdés Lucas et al. 2016). Thus, renewables can balance the price volatility of fossil fuels, as fossil fuels and renewables are uncorrelated (Valdés Lucas et al. 2016). Renewable energy sources also decrease energy vulnerability via diversification of the energy mix concerning both energy sources and technologies (Valdés Lucas et al. 2016).

Regarding the three perspectives of energy security as mentioned by Cherp & Jewell (2011): the ‘sovereignty’ based in political science, the ‘robustness’ based in natural science and engineering and the ‘resilience’ based in economics and complex systems analysis, Valdés Lucas et al. (2016) state that renewable energy sources can contribute to ameliorate energy security in these three dimensions. Concerning sovereignty, renewables are less vulnerable to physical assault or the utilization of energy as a political weapon, as a domestic and decentralized energy supply (Valdés Lucas et al. 2016). Renewable energy sources contribute to the diversification of energy sources, routes and geographical origins compared to the oligopolistic character of conventional energy firms, renewables can prevent market power abuse (Valdés Lucas et al. 2016).

In terms of robustness, renewables also mitigate threats in the energy system mostly risks of technical failures, despite their fluctuating nature and their required back up capacity, due to their decentralization (Valdés Lucas et al. 2016). In terms of resilience, renewables significantly contribute to technological change in energy, as cutting-edge technology remains at the forefront of research and development programs (Valdés Lucas et al. 2016). Renewable sources also permit technological diversification among different technologies, researching different development trails mitigating climate change and energy price volatility (Valdés Lucas et al. 2016).

2.3.3 Impediments of renewable energy sources

Besides the benefits of renewable energy, there are also some impediments concerning the implementation of renewable energy technologies. Johansson (2013, b) states that renewable sources rely on climate conditions. While Valdés Lucas et al. (2016) mention a negative aspect of renewable energy sources, the fact that they are not entirely “dispatchable” as a result of their fluctuating disposition. So, in the event of uninterrupted energy requirements renewables cannot be the only solution.

Ryberg et al. (2018) also point out that technologies of renewable energy are intermittent and locally dependent on power production. Bekun et al. (2019) mention that ‘intermittency and stability’ are concerns of renewable energy technologies. According to Olz et al. (2007), renewable energy technologies rely on different natural cycles and for this reason vary on different time scales. At high-level penetration of renewables, it is noticed unmatched demand and supply and this feature can raise issues for grid management in order to supplant these capacities (Olz et al. 2007). So, the supplementary cost for grid back-up, electricity storage and rotating reserve must be considered (Olz et al. 2007). Moreover, substantial portions of only variable sources, like wind, demand manners to balance the supply with the load (Olz et al. 2007). Olz et al. (2007) also mention that control methods along with back-up available capacity can cope with ever-changing power demand in several countries, at penetration levels up to 20%. So, enhanced control technologies, more precise forecasting techniques and increased geographical dispersal as stated by Olz et al. (2007), contribute to the effective integration of renewables.

In addition, a balanced portfolio of renewables with various natural cycles as mentioned by Olz et al. (2007), might diminish the necessity for back-up capacity. However, rigorous analysis is required concerning the effect of large-scale penetration in the power grid of variable renewables (Olz et al. 2007). Therefore, Olz et al. (2007) claim that according to the balance of available capacity and to connectivity of the system, investment may be required in back-up capacity and in policies as well to improve demand side response. Renewable technologies usually supplant conventional generation technologies used for base load, such as coal, natural gas and nuclear based on the extent to which variable renewable technologies predominate in a power network (Olz et al. 2007).

Impram et al. (2020) also point out the term of flexibility in power systems as the ability to provide supply-demand balance, preserve continuity in unforeseen circumstances, and handle supply-demand uncertainty. As mentioned by Impram et al. (2020), in conventional power systems flexibility is ensured by supply reserves and generation planning. Nevertheless, in current power systems where the penetration of renewables is constantly increasing flexibility obtains a new aspect, due to issues occurred by generation uncertainty and availability notions (Impram et al. 2020).

At high-level penetration of renewables, as mentioned by Impram et al. (2020), renewables "have dispatch priority" and through high generation seasons, the demand is mostly supplied by them. Hence, baseload plants' generation should be reduced or stopped when generation based on renewable energy is adequate; however, when generation based on renewable energy is interrupted or halts, the baseload power stations must be "re-commissioned" (Impram et al. 2020). According to Impram et al. (2020), stability is essential for the reliable and uninterrupted power system's operation. The penetration level of wind and solar technologies and their connection topologies, as claimed by Impram et al. (2020), affect voltage stability, small-signal, transient and frequency stability of power systems. Supply-side flexibility in a power grid can be accomplished via generation and demand-side management and appropriate planning and operation of transmission networks (Impram et al. 2020).

Another potential risk of renewable energy technologies according to Johansson (2013, b) is the attacks by non-state actors on renewable electricity facilities pointing to the vulnerability of the power grid which differs among technologies. Johansson (2013, b) mentions that offshore photovoltaic and wind energy technologies appear to be less vulnerable than onshore concentrated solar and wind power. Furthermore, Johansson (2013, b) also distinguishes physical and virtual attacks on electricity grids, concluding that these cannot be eliminated.

As previously stated, the extensive expansion of renewable energies in the global energy mix may induce new dependencies (Hache 2018). Proskuryakova (2018) states that the competition for energy resources will be replaced by the competition for energy conversion and storage technologies, smart-grid solutions and high-speed energy transmission systems. According to Hache (2018), the reliance on fossil energy resources could be substituted for reliance on strategic metals such as raw materials like rare metals, rare earth metals, battery components metals such as cobalt and lithium, traditional non-ferrous market components including copper, tin, nickel and more industrialized market components such as cement and steel but also water. Therefore, as mentioned by Hache (2018) the broad diffusion of energy transition technologies can trigger or increase tensions in those commodity markets. Johansson (2013, b) also points out that the resources of scarce materials, including tellurium, ruthenium and indium for solar energy, lithium for batteries for electric vehicles, platinum for fuel cell vehicles and neodymium for wind power plants, are gathered to a few countries and considered as potential causes of hostilities. Even though these resources can be extremely precious, the degree of reliance alters and future reliance will rely on the availability of substitutes (Johansson, 2013 b). Some of these materials, as mentioned by Johansson (2013, b), can be substituted for other, more plentiful resources at an equivalent economic cost. Besides, the long-term supply of these metals will also rely on the improvement of efficient recycling systems (Johansson, 2013 b).

Moreover, social aspects such as social acceptance of renewables and the disturbance of local citizens are also important. According to Stigka et al. (2014), there are three parameters that determine public behavior: the public’s information, perceptions and positions, and third fear, danger or anxiety that deepens due to ignorance. Stigka et al. (2014) point out that acceptance of renewables increases among people who possess adequate information and participate in the decision-making process. In addition, individual consumers, as mentioned by Stigka et al. (2014), favor solar energy followed by wind power and biomass. While, inhabitants question the reliability of renewable energy, local communities might respond negatively to close renewable investments according to the NIMBY -Not in My Back Yard- the phenomenon by which there is public resistance to a project rejected by the local community and it may lead to social conflict and economic damage (Stigka et al. 2014). Johansson (2013, b) also mentions conflicts over land use.

Drawbacks of renewables as stated by Stigka et al. (2014), comprise beyond the environmental impact on flora and fauna, alterations in the aesthetics of the landscape and visual intrusion of facilities, noise pollution and significant installation costs. Ryberg et al. (2018) also mention the effect of sociotechnical criteria such as environmental protection, disturbance to local inhabitants and inappropriate fields on the distribution of renewables over a region. The impediments of solar energy technologies according to Tsoutsos et al. (2005), are "minor" and commonly affiliated with the deprivation of amenities as visual impact or noise through the installation and the demolition. While these effects, as stated by Tsoutsos et al. (2005), can be reduced with "alleviation techniques" as listed in Table 4.

Saidur et al. (2011) claim that besides the impacts on wildlife, noise and visual impact are the most adverse effect of wind energy. The visual impact differs based on the wind energy technology including color or contrast, shadow flickering, size, distance from the dwellings, local turbine history and the time when the turbine is moving or it is stationary (Saidur et al. 2011). According to Saidur et al. (2011), the visual impact of wind turbines increases in stationary status since blades are difficult to be noticed when the turbine is moving. The noise created by wind turbines irritates the locality of the installation project (Saidur et al. 2011). According to Leung & Yang (2012), wind turbines' noises distinguish between mechanical noise and aerodynamic noise. Low-frequency aerodynamic noise can hassle inhabitants inducing sleep disturbances, and hearing loss and harm the vestibular system (Leung & Yang 2012). However, these drawbacks could be overcome, as stated by Leung & Yang (2012), by placing obstacles in the propagation path and by building wind turbines at least 2 km away from inhabited areas.

In addition, electromagnetic interferences are also considered negative effects of wind energy (Sayed et al. 2020). Wind turbines can influence close navigation, microwave communication, television, and FM radio systems via modulating radio wave radiation (Sayed et al. 2020). Saidur et al. (2011) also mention the risk of a wind turbine being hit by lightning and the distraction radar or television reception because of magnetic forces.

Table 4: Solar energy technologies' negative impacts (Tsoutsos et al. 2005)

Impacts–burdens	**Alleviation technologies/techniques**
Solar thermal heating	
Visual impact on buildings' aesthetics	Adoption of standards and regulations for environmentally friendly design; Good installation practices Improved integration of solar systems in buildings; Avoid siting of solar panels on buildings of historic interest or in conservation areas
Recycling of the used chemicals;	Recycling of the used chemicals; Good practices - appropriate disposal
Land use	Proper siting and design.
Photovoltaic power generation	
Land use: large areas are required for central systems.	Use in isolated and deserted areas;
Reduction of cultivable land	Avoidance of ecologically and archeologically sensitive areas; Integration in large commercial buildings (facades, roofs); Use as sound isolation in highways or near hospitals.
Visual intrusion – aesthetics	Careful design of systems; Integration in buildings as architectural elements; Use of panels in modern architecture instead of mirrors onto the facade of buildings
Impact on ecosystems (applicable to large PV schemes).	Avoidance of sensitive ecosystems and areas of natural beauty, archaeological sites.
Use of toxic and flammable materials (during construction of the modules)	Avoidance of release of potentially toxic and hazardous materials with the adoption of existing safety regulations and good practice.
Slight health risks from manufacture, use & disposal	Good working practices (use of protecting gloves, sunglasses, clothing during construction).
Solar thermal electricity	
Construction activities	Good working practices; Site restoration; Avoidance of sensitive ecosystems and areas of natural beauty.
Visual impact – aesthetics	Proper siting (avoidance of sensitive ecosystems and areas of natural beauty, densely populated areas).
Land use	Proper siting.
Effect on the ecosystem, flora and fauna (especially birds)	Proper siting (avoidance of sensitive ecosystems).
Impact on water resources water use (for cooling of steam plant) and possibly, water pollution due to thermal discharges or accidental discharges of chemicals used by the system	Appropriate constraints (not the excessive use of existing resources); Improved technology (use of air as heat-transfer medium); Exploitation of the warm water in the nearest industry in the production stream. Good operating practices and compliance with existing safety regulations; Employees should be educated and familiarized with the systems.
Safety issues (occupational hazards)	

Besides the drawbacks and the impediments of renewable energy technologies, their use induces certain environmental impacts. In the following chapter, the environmental impacts of renewable energy technologies are examined, including the interconnection between energy security and the environment.

2.4 Energy security and the Environment

There is no form of energy production or use without environmental implications (Azzuni & Breyer 2017). Even though renewable energy sources have unambiguous environmental profits in comparison with conventional sources, they are not free of negative impacts (Sovacool 2014). Despite the implementation of renewables, every kilowatt-hour of electricity generated, every cubic foot of natural gas produced, every barrel of oil provided or every ton of uranium excavated generates variable environmental effects including potentially radioactive waste and deserted uranium mines, acid rain and its impact to crops and fisheries, water deterioration and immoderate consumption, particulate pollution and accumulative environmental destruction to ecosystems and its biodiversity (Sovacool, 2012; 2014). The importance of energy impacts on environmental systems implies strong correlations to energy security (Sovacool 2014). Besides, as mentioned by Azzuni & Breyer (2017), an energy system vigorously affects the environment hence the environmental dimension should be contained in the energy security discussion. Table 5 indicates the four environmental dimensions of energy security in Asia and the Pacific according to Sovacool (2014): climate change, air pollution, water availability and quality, and land-use change.

Table 5: Environmental Dimensions of Energy Security in Asia and the Pacific (Sovacool 2014).

Dimension	Link to Energy Security	Energy Contribution to The Problem
Climate Change	▪ Climate change is a “threat multiplier” in terms of energy security. ▪ Mass migrations of refugees seeking asylum from ecological disasters could destabilize regions of the world threatening energy as well as national security.	A total of 66.5% of global carbon dioxide emissions come from energy supply and transport

Dimension	Link to Energy Security	Energy Contribution to The Problem
Air Pollution	Deterioration of environmental conditions can negatively impact human and ecological health with significant numbers of premature deaths related to indoor and outdoor air pollution and significant expenditures lost in terms of lost productivity and healthcare.	About 80% of global sulfur dioxide emissions, 80% of particulate matter emissions, and 70% of nitrogen oxide emissions come from the energy and transport sectors.
Water Availability and Quality	▪Lack of available safe drinking water can destabilize the security of a region. ▪Because fossil, hydro, and nuclear power plants consume large quantities of freshwater, shrinking supplies of water could threaten the ability to provide electricity and the ability of nations to feed themselves.	In all, 25% of global water supply is lost due to evaporation from reservoirs and another 10%–15% of global freshwater is used in thermoelectric power plants.
Land-Use Change	Deforestation can cause social dislocation, increase the cost of fuelwood, destroy biodiversity, and conflict with agriculture and the preservation of nature reserves**.**	At least 15% of land-use change is caused by the direct clearing of forests for fuelwood and the expansion of plantations for energy crops

Climate change constitutes a significant energy security concern as it can cause severe damages including floods and natural disasters threatening power plants and transmission lines, disrupting the delivery of energy supplies and causing serious effects on food security and health (Sovacool 2014). The negative impact of climate change, including increasing temperatures, rising sea levels, extreme winds and decreased rainfall, may affect renewable energies (Osman et al. 2022) Besides, renewable resources depend on long-term climate and short-term weather patterns (Johansson 2013, b).

Climate change can modify atmospheric dynamics, altering wind patterns regarding spatial distribution and temporal variability and jeopardizing wind power generation (Osman et al. 2022). According to Osman et al. (2022) in future climate scenarios, it is mentioned a general decline in wind energy; more precisely wind energy is anticipated to lessen by roughly 6% in the summer and augment faintly by 1.1% in winter. Wind energy and hydropower production can be diminished by 40% in certain areas because of climate change, while solar energy seems the least affected energy source (Osman et al. 2022). Climate change has also a negative effect on biomass productivity since climate change issues and extreme weather conditions can destroy specific organisms and therefore reduce biodiversity (Osman et al. 2022). On the contrary, geothermal energy will not be impacted by climate change since it is mainly affected by the structure of the earth's crust and the physical processes inside the earth's interior (Osman et al. 2022). Geothermal energy supplies base-load power for daily living, no matter seasonal issues or climate change (Osman et al. 2022). So, as mentioned by Osman et al. (2022), geothermal energy has “the greatest potential value among all renewable energy sources”.

Air pollution is also an energy security concern (Sovacool 2014). Sovacool (2014) states that 80% of SO_2 emissions, 80% of particulate matter (PM) emissions, and 70% of nitrogen oxide emissions derive from the energy and transport sectors.

Even though agriculture is considered the major consumer of freshwater, the energy field is ranked second with hydropower, nuclear power, and thermal power generation considered about 10% to 15% of global water consumption (Sovacool 2014). The energy sector utilizes and pollutes water sources; thermoelectric power plants which are based on coal, oil, natural gas, biomass, or uranium in nuclear reactors extract water from streams, rivers and lakes to chill equipment before restoring it to its source, and they consume it during evaporative loss (Sovacool 2014). Osman et al. (2022) mention that apart from biomass energy, all renewable energy sources affect aquatic environments. In reverse, alterations in the runoff, rainfall and streamflow frequency due to climate changes influence hydropower power production (Osman et al. 2022). According to Osman et al. (2022), the future efficiency of hydropower energy in most countries will diminish, at the upper limit decrease of 41% in hydropower generation.

Energy production can also affect land in several ways such as deforestation and soil erosion (Sovacool 2014). Considering that, it is crucial to assess the impact of each renewable technology type on the environment with major focus on the air, water, land and human aspects. This is the topic of the subsequent section.

2.4.1 Environmental impact of renewable energy technologies

Every energy source has different environmental effects based on energy source type, location, scale, and implementation method (Osman et al. 2022). The environmental impacts of energy systems are briefly presented in Table 6 according to Sovacool 2014.

Table 6: Impacts of Energy Systems on Climate Change, Air Pollution, Water Availability and Quality, and Land-Use Change (Sovacool 2014).

Energy System	Climate Change	Air Pollution	Water	Land Use
Energy efficiency	Minimal	Minimal	Minimal	Minimal
Nuclear power	Moderate	Minimal	Severe	Severe
Shale gas	Severe	Severe	Severe	Severe
Conventional coal	Severe	Severe	Severe	Severe
Clean coal	Moderate	Severe	Severe	Severe
Oil and gas	Severe	Severe	Severe	Severe
Hydroelectricity	Minimal	Minimal	Severe	Moderate
Wind energy	Minimal	Minimal	Minimal	Moderate
Solar photovoltaics	Minimal	Minimal	Minimal	Moderate
Solar thermal	Minimal	Minimal	Moderate	Moderate
Geothermal	Minimal	Minimal	Moderate	Moderate
Biomass	Minimal	Moderate	Moderate	Moderate
Biofuels	Minimal	Moderate	Severe	Severe

Meanwhile, Table A.1 in the Appendix presents all the environmental impacts of each type of renewable source as mentioned by Osman et al. (2022). According to Osman et al. (2022), wind and biomass energy are “the most environmentally friendly energy sources”, while hydroelectric power plants are considered “the most damaging” to the environment in comparison with other renewable energy sources. Hydropower is the oldest renewable energy source, with considerable implications on the environment. Nevertheless, with the careful management of its implementation, the successful mitigation of its environmental impact is possible.

2.4.1.1 Hydroelectricity

Hydroelectricity as mentioned in Table 6, causes severe water effects while moderate land-use effects and minimal air pollution and climate change impacts (Sovacool 2014). Osman et al. (2022) also state that hydroelectric power plants are the most harmful to the environment among renewable energy sources. Hydroelectric power plants can degrade soil quality by inducing desiccation and erosion of soil (Osman et al. 2022). Concerning air pollution, hydroelectric power plants cause changes in temperature and precipitation triggered by greenhouse gas emissions (Osman et al. 2022). According to Osman et al. (2022), hydropower induces eutrophication and augmentation in suspended sediments, changes in lagoons and deltas, induces floods and changes in water temperature and oxygen levels. Sovacool (2014) also mentions that sedimentation, ecosystem destruction and water quality are environmental issues rising for hydroelectric dams as it is a "physical barrier" disturbing water flows for rivers, lakes and streams disrupting the locomotion of species and changing upstream and downstream habitats (Sovacool 2014). Finally, as mentioned by Sebestyén (2021), the most significant effects of hydropower are 'changes in river flow regime', 'groundwater regime sinking', 'heavy metal pollution', 'river-bank erosion' and 'noise'.

2.4.1.2 Wind Energy

According to Sovacool (2014), wind energy poses moderate land-use effects and minimal environmental effects over the other three dimensions. Even though wind power plants have comparatively minor effects on the environment in comparison with fossil fuel power plants, there are issues concerning visual impacts, the noise produced by the rotor blades and deaths of birds and bats that fly nearby the rotors (Saidur et al. 2011). Sebestyén (2021) claims that the most commonly correlated environmental effects of wind energy are 'offshore wind farm new habitat impact', the 'thrown ice', 'climate change', 'bat fatality' and 'bird disturbance'. While Sayed et al. (2020) mention that noise pollution is the most obvious negative environmental impact of wind energy systems. Noise is identified as any "irritating or disturbing sound" (Sayed et al. 2020). Regarding wind turbines, as mentioned by Sayed et al. (2020), noisy, disagreeable sounds can be induced by aerodynamics as the wind with different velocities crosses the wind turbine blades with different dimensions. According to Sayed et al. (2020), the environmental impacts of wind energy are in brief: noise and visual, bird fatality, soil erosion and deforestation, lightning from towers, electromagnetic radiation, and surrounding neighborhood.

Concerning bird fatality, as mentioned by Sayed et al. (2020) it is statistically concluded that wind power plants related to bird fatality are remarkably lower than different causes such as building collision, human activities and utility projects. Saidur et al. (2011) also claim that wind energy as a source of energy, is the most compatible with animals and human beings, underlying the fact that climate change constitutes a far more substantial threat to wildlife. Besides, as stated by Saidur et al. (2011) the proper position of wind plants mitigates birds' mortality. In addition, Leung & Yang (2012) point out that local birds can promptly learn to bypass barriers and therefore wind turbines are not a severe issue for them. So, the number of birds that died from wind turbines is considered negligible in comparison with other human activities (Saidur et al. 2011; Leung & Yang 2012). In particular, as mentioned by Saidur et al. (2011), the total number of birds deaths owing to wind turbines, in a year, is only 20 for an installed capacity of 1000 MW, whereas 1.500 deaths are provoked by hunters and 2.000 induced by collisions of transportation's means and electricity transmission lines which are nearly 'invisible' for birds.

Even though wind power plants are characterized as environmentally friendly since they emit approximately zero pernicious chemical compounds in the atmosphere throughout their operation phase, their manufacturing and their "post-use management" after their end-of-life induce various environmental risks that according to Piotrowska & Piasecka (2021), are seldom mentioned. Wind power plants are constituted the majority of by plastics and materials that can be recycled easily such as steel used in the manufacture of the tower or ductile iron of hubs (Piotrowska & Piasecka 2021). Figure 4 depicts the construction of a typical wind power blade. The recyclable components of wind power plant blades comprise as mentioned by Piotrowska & Piasecka (2021), 85 to 90% of their weight. However, wind power plant blades are also made of polymer materials, inducing several issues through the post use management stage (Piotrowska & Piasecka 2021). According to Piotrowska & Piasecka (2021), polymer plastics cause tremendous damage to the environment as the vast majority of these composite materials are "extremely persistent" demanding hundreds of years in order to decompose. Landfill, incineration, transmutation to new items and recycling are as stated by Piotrowska & Piasecka (2021), methods of polymer waste management.

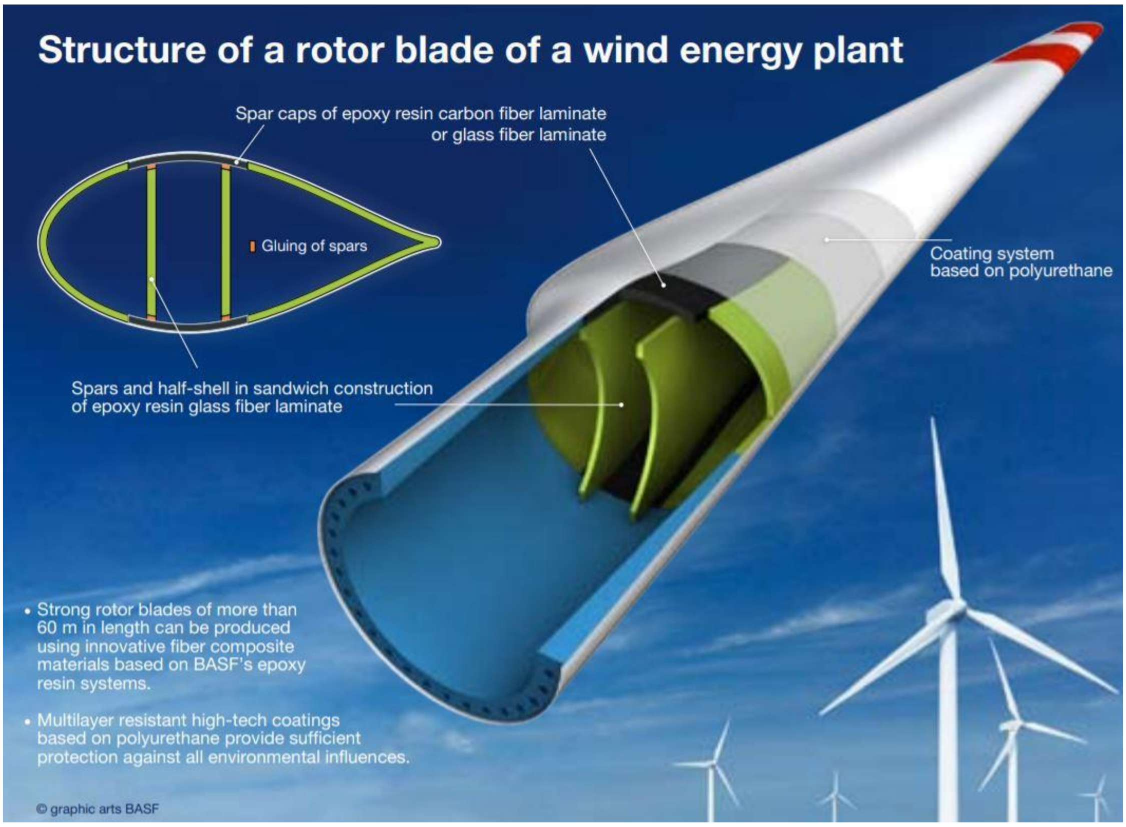

Figure 4: A cross-section of a wind power plant blade including key materials and components (Piotrowska & Piasecka 2021)

2.4.1.3 Solar Photovoltaics

According to Sovacool (2014), solar photovoltaics induce moderate land-use effects and minimal environmental consequences to the other three dimensions. The land-use effects are based on the implementation of perilous components including silicon which has to be extracted and there is a risk of contamination of land in case of malfunction or destruction of systems or due to storms and hurricanes (Sovacool 2014). Sebestyén (2021) mentions that the most considerable environmental effects of solar power plants are ‘Erosion’, ‘Visual impact’, ‘Release of soil-borne pathogens’, ‘Depletion of natural resources’ and ‘Toxic materials in panels’.

In fact, Rathore & Panwar (2022) focus on the environmental impact of photovoltaic materials considering the effect of waste solar panels on the environment and the concern of suitable disposal of waste panels. According to Hosenuzzaman et al. (2015), photovoltaic systems have an insignificant impact on greenhouse gas emissions. While Rathore & Panwar (2022) state that solar-powered generation of electricity is exempt from noise and toxic greenhouse gas emissions. Nevertheless, the photovoltaic industry is affiliated with the utilization of pernicious and toxicant chemical substances (Rathore & Panwar 2022).

Solar waste has recently been classified in the category of waste electrical and electronic equipment, while photovoltaic technology is assessed on a life cycle analysis and end-of-life management (Rathore & Panwar 2022). Tsoutsos et al. (2005) also mention waste management of “stand-alone” PV systems denoting that their batteries induce serious environmental effects because of their heavy metal substances and their relatively brief lifetime. Current photovoltaic (PV) panels have a lifetime of 25 years and photovoltaic technology deteriorates as entering the end-of-life phase (Rathore & Panwar 2022). The number of PV panels approaching their end-of-life point, would augment at an exponential rate as PV installations expand, turning into hazardous waste (Rathore & Panwar 2022). Approximately as mentioned by Rathore & Panwar (2022), 200,000 tonnes of solar PV waste will be produced by 2030 and they are expected to increase to about 1.8 million tonnes by 2050. While they also mention that this renewable waste will increase by around 60 million tonnes worldwide. Every 1 MW of solar PV installed capacity produces roughly 75 MT (metric tonnes) of solar waste (Rathore & Panwar 2022).

Moreover, throughout the manufacturing process of solar panels, several hazardous components, including lead (Pb), cadmium (Cd) compounds and polymers are applied (Rathore & Panwar 2022). However, the quantities of these substances such as Cd and Pb are modest Rathore & Panwar (2022) claimed the current recycling procedures for solar panels are extended and difficult. In addition, elements such as gallium (Ga), indium (In) and germanium (Ge) are also used in PV panels' production, through only silicon, applied in the panel terminals, could be recycled (Rathore & Panwar 2022). Other byproducts of this manufacturing procedure are sulfuric acid (H_2SO_4), hydrogen fluoride (HF), hydrochloric acid (HCl) and nitric acid (HNO_3) (Rathore & Panwar 2022). The quantity of chemical substances used relies on the type of cell produced (Rathore & Panwar 2022). According to Rathore & Panwar (2022), conventional silicon PV technology comprises fewer toxic substances than thin film PV technology. The film PV cells comprise substances such as gallium (Ga), selenium (Se), telluride (Te^{-2}) and indium (In), substances which have to be cautiously disposed of to prevent hazardous environmental and health issues.

Furthermore, compounds and solvents such as hydrochloric acid (HCl), nitric acid (HNO_3), hydrogen fluoride (HF), acetone (C_3H_6O) and ethanol (C_2H_6O) are applied to purifying wafers through the fabrication procedure (Rathore & Panwar 2022). Approximately 37% of these wastes are released in external treatment facilities though 35% of wastes are emitted as diluted acid solutions to processing facilities while 0.8% of these wastes are stated to be discarded into surface water (Rathore & Panwar 2022). In addition, substances such as cadmium, lead and polymer are discarded in an unconstrained manner causing potential environmental degradation and health problems for instance; Cadmium telluride (CdTe) can induce serious pulmonary inflammation and fibrosis (Rathore & Panwar 2022). Additionally, the leaching of lead (Pb) can affect the reproductive rate in animals and plants, inducing species extinction and diverse other health problems in kidney function and immune and nervous systems (Rathore & Panwar 2022).

Back sheets and encapsulants of PV panels are produced by polymer fractions composed of non-recycling fluorinated and cross-linked plastics (Rathore & Panwar 2022). Additional burning of this polymer during the incineration phase expels corrosive gases able to harm the ecosystem in case of inappropriate disposal (Rathore & Panwar 2022). Figure 5 illustrates the components of solar modules, their commercial value, recyclability, waste classification and their environmental impact as mentioned by Rathore & Panwar (2022).

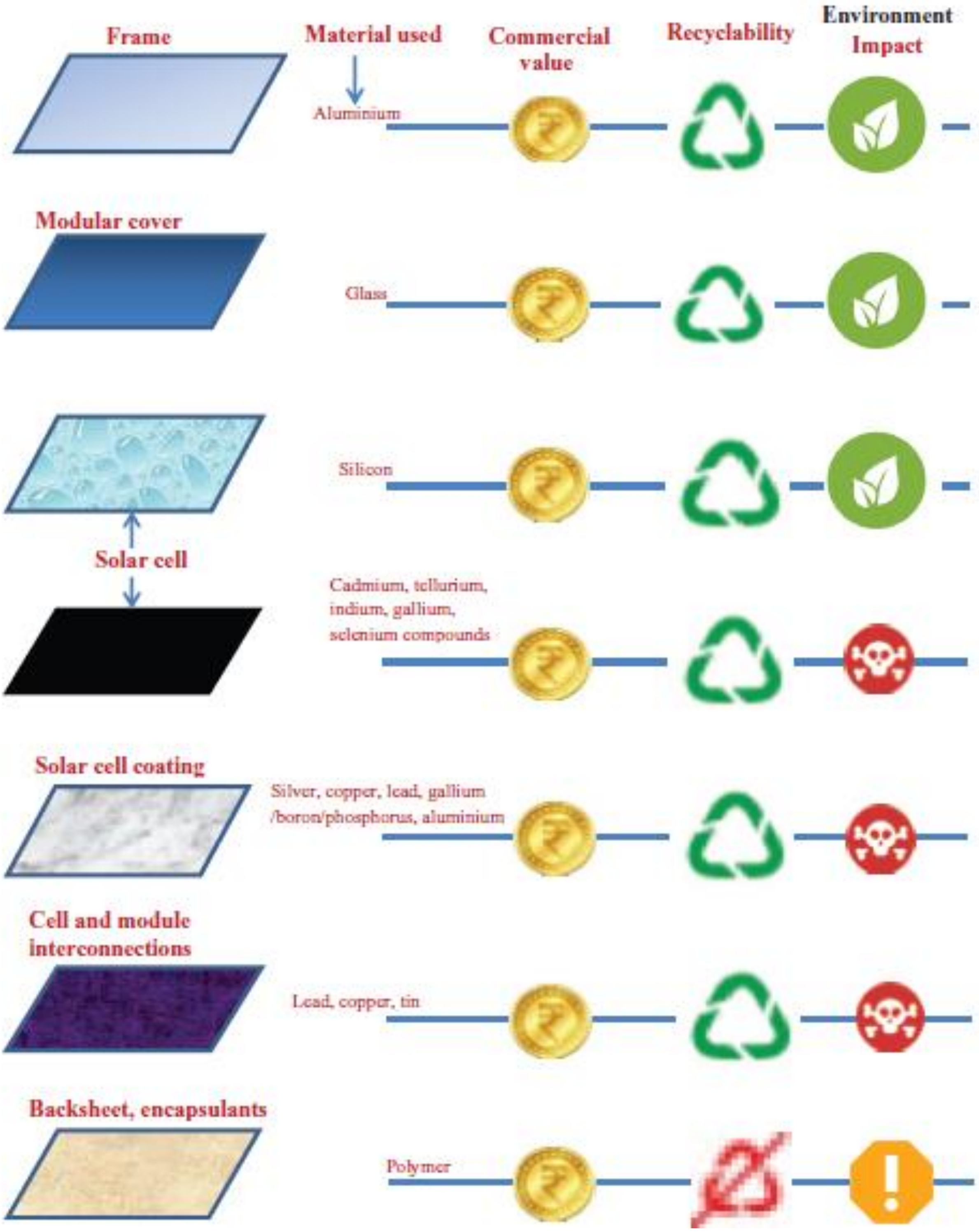

Figure 5: Waste classification of PV modules along with their environmental impact (Rathore & Panwar 2022)

2.4.1.4 Solar Thermal

Solar thermal and concentrated systems demand significantly more water and expanses of land as well (Sovacool 2014). Tsoutsos et al. (2005) state that this requirement for water can cause a considerable strain on water sources. The potential risk of water pollution during thermal emissions and in case of accidents is also mentioned by Tsoutsos et al. (2005). Osman et al. (2022) also mentioned that solar photovoltaics and concentrated solar power produce greenhouse gas emissions and ozone depletion.

2.4.1.5 Geothermal

According to Sovacool (2014), geothermal technology has moderate water effects and minimal environmental effects in the other dimensions. Even though geothermal plants can expel minor quantities of hydrogen sulfide (H_2S) and CO_2 as well as toxic sludge comprising sulfur, silica compounds, arsenic (As) and mercury (Hg), these substances can be restrained by pollution control equipment (Sovacool 2014). Sebestyén (2021) states that the environmental effects of geothermal power plants are ‘‘Noise’’, ‘‘Hydrothermal eruptions’’, ‘‘Greenhouse gas emission’’, ‘‘Ground collapse/subsidence’’ and ‘‘Increase in the frequency of seismic events’’.

2.4.1.6 Biomass

Biomass energy according to Sovacool (2014) has minimal climate change effects, though moderate environmental effects on air pollution, water, and land use exist. During biomass combustion, zero amounts of CO_2 are released into the atmosphere, while the quantifiable amount of a broad range of pollutants into air, land, and water are emitted (Sovacool 2014). Johansson (2013, b) mentions that the expanded implementation of bioenergy can cause stress on water sources since bioenergy systems depended on irrigation. According to Sayed et al. (2020), the implementation of biomass requires considerably more water than ordinary domestic and industrial demands meanwhile extensive acreages of land are also required. Soil erosion and water run-off as a result, withdrawal of soil nutrients as bioenergy crops demand large amounts of nutrients and synthetic fertilizers are needed, deprivation of wildlife, territory and soil biota consisting of the micro-organisms as a result of displacement of other crops, forests, and natural land and therefore reduction of biodiversity are the environmental impacts of biomass as mentioned by Sayed et al. (2020). Sebestyén (2021) also states that the impacts of a biomass power plant mainly rely on its anticipated performance while this renewable energy source has the minimal capacity to diminish its damaging effects.

Mahmud et al. (2019), present a comparative study among solar PV, biomass, and pumped storage hydropower plants in the United States comparing their environmental effects via a systematic Life Circle Assessment (LCA) analysis according to which solar PV systems are the most environmentally friendly among the other renewable sources, as they release lesser greenhouse gas emissions in the following quantities: carbon dioxide (CO_2) (4.03E-06 kg CO_2-eq./kWh), methane (CH_4) (1.62E-07 kg CO_2-eq./kWh) and nitrogen oxide (NOx) (1.42E-07 kg CO_2-eq./kWh). In addition, the entire environmental effects for all the "end-point indicators", such as human health, ecosystem quality and resources, are lesser in solar PV plants than in others (Mahmud et al. 2019). Moreover, biomass power plants induce medium harm to the environment apart from smog and ozone-layer depletion according to Mahmud et al. (2019). While Stanek et al. (2016) claim that biogas power plants induce fewer environmental effects than wind and photovoltaic technologies, whereas Osman et al. (2022) state that wind energy and biomass systems have a negligible environmental impact.

Eventually, comparing the environmental effects among solar PV, biomass, pumped storage hydropower, nuclear, natural gas and bituminous coal plants, as stated by Mahmud et al. (2019), bituminous coal induces the greatest effect on global climate change (1.1 kg CO_2-eq./kWh) and eutrophication (1.99E-04kg N-eq./kWh). Natural gas has the upper limit impact on ozone depletion (6.38E-08 kg CFC-11 eq./kWh), carcinogenics (3.01E-09 CTUh/kWh), ecotoxicity (9.60E-01 CTUe/kWh) and fossil-fuel exhaustion (9.60E-01 MJ/kWh), while biomass systems have the maximum impact on smog (2.41E-01 kg O_3-eq./kWh) as mentioned by Mahmud et al. (2019).

Therefore, renewable energy sources induce considerably less environmental impact than fossil resources (Sayed et al. 2020), and even though the adverse impact of intermittent renewable energy resources (Stanek et al. 2016) all of these systems, are regarded as a better alternative considering conventional energy systems and environmental sustainability (Sayed et al. 2020).

3. Conclusions

This thesis comprises a literature review of environmental and renewable energy aspects of energy security. In order to interpret the term energy security, a historical overview of the notion of energy security and how the concept has evolved over the years, are provided along with the transition of the world's energy regime. Energy security was initially intertwined with security of supply. The notion of energy security though evolves, expands and is modified along with changes in geopolitics, economic transition and environmental security.

There is not only one definition of energy security therefore; the definitions of energy security defined by international organizations are presented as well. International literature agrees that energy security is a multi-dimensional concept that is built upon different components which differentiate during different time periods and in different areas. Each dimension consists of components and each component can be computed by metrics, quantitative or qualitative indicators. New dimensions and components are being added, such as cyber security, representing the current energy security risks. However, no matter how energy security is defined, the complexity of interconnected environmental issues and the related social and economic concerns are the most important issues.

In the context of this literature review, the contribution of renewable energy to the dimensions of energy security is also examined. Renewable energy is a game changer in terms of energy security, constituting an energy security indicator. Considering this, the contribution of renewable energy to energy security is thoroughly presented under and beyond the definition of 4 As. According to the international literature, renewable energy sources enhance availability, affordability, acceptability and accessibility. Renewable energy sources can also lessen energy primary, secondary and exposure risks and vulnerabilities. Besides their benefits, there are some challenges to address regarding the implementation of renewable energy technologies such as, intermittency, stability, dependence on the availability of different components such as rare metals, crucial in these technologies, social acceptance and negative environmental impacts.

Nevertheless, there is no form of energy production or use without environmental impact. In this regard, the examination of the environmental effects of the most important renewable energy technologies indicates that among them, hydroelectric power plants are the most harmful to the environment whereas; wind energy and biomass systems have a negligible environmental impact.

In conclusion, renewable energy sources enhance energy security and induce considerably less environmental impacts than fossil resources. So, they are regarded as a better alternative considering conventional energy systems and environmental sustainability.

Appendix

Table A.1: Environmental effects of different renewable energy sources (Osman et al. 2022).

	Environmental impact	Solar	Solar thermal	Wind	Biomass	Geothermal	Hydropower
Air	Greenhouse gas	Moderate impact	Moderate impact	Negligible	Negligible	Moderate impact	High impact
	Ozone layer	Moderate impact	Negligible	Negligible	Negligible	Negligible	Negligible
	Air pollution	Moderate impact	Negligible	Negligible	Negligible	Moderate impact	Negligible
	Air toxification	Moderate impact	Moderate impact	Negligible	Moderate impact	Moderate impact	Negligible
	Change in air temperature	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Change in air precipitation	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
Water	Water pollution	Moderate impact	Moderate impact	Moderate impact	Negligible	Moderate impact	Moderate impact
	Water toxification	Negligible	Negligible	Moderate impact	Negligible	Moderate impact	High impact
	The mating process of fish	Negligible	Negligible	Moderate impact	Negligible	Negligible	Moderate impact
	Fish migration	Negligible	Negligible	Moderate impact	Negligible	Negligible	Moderate impact
	Change in water temperature	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Impact of water flow	Negligible	Negligible	Negligible	Negligible	Negligible	High impact
	Change in water salinity	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Effect on suspended sediments	Negligible	Negligible	Negligible	Negligible	Negligible	High impact
	Eutrophication	Moderate impact	Negligible	Negligible	Negligible	Negligible	High impact
	Affecting aquatic habitat	Negligible	Negligible	Moderate impact	Negligible	Negligible	Moderate impact
	Fish decline	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Flooding	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Dried up rivers	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Water oxygen level	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Affecting deltas and lagoons	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Fisheries influences	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Coastline defense	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible

	Environmental impact	**Solar**	**Solar thermal**	**Wind**	**Biomass**	**Geothermal**	**Hydropower**
Soil	Land requirement	Moderate impact	Moderate impact	Moderate impact	High impact	High impact	High impact
	Soil pollution/ disturbance	Moderate impact	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Soil toxification	Moderate impact	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Desiccated soil	Moderate impact	Negligible	Moderate impact	Negligible	Negligible	High impact
	Soil erosion	Negligible	Negligible	Moderate impact	Negligible	Negligible	High impact
	Affecting irrigation	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Mangrove forests	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
	Affects soil efficacy	Moderate impact	Moderate impact	Moderate impact	Negligible	Negligible	Negligible
	Deforestation	Moderate impact	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Effect on vegetation	Moderate impact	Moderate impact	Moderate impact	Negligible	Negligible	High impact
	Seismic activity	Negligible	Negligible	Negligible	Negligible	High impact	High impact
	Relocation of wild animals	Moderate impact	Negligible	Negligible	Negligible	Negligible	Negligible
	Affecting terrestrial habitat	Moderate impact	Moderate impact	Negligible	Negligible	Negligible	Negligible
Human	Human health	Moderate impact	Negligible	Moderate impact	Negligible	Moderate impact	Moderate impact
	Disturbance to humans	Negligible	Moderate impact	Moderate impact	Moderate impact	High impact	High impact
	Relocation of native residents	Moderate impact	Negligible	Moderate impact	Negligible	High impact	High impact
	Visual disturbance	Negligible	Moderate impact	Moderate impact	Negligible	Negligible	Negligible
	Unpleasant smell	Negligible	Negligible	Negligible	High impact	Moderate impact	Moderate impact
	Natural aesthetic affected	Negligible	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Tourism potential affected	Negligible	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Archaeological places affected	Negligible	Negligible	Negligible	Negligible	Negligible	Moderate impact
Miscellaneous impacts	Availability based on time	Moderate impact	Moderate impact	Moderate impact	Beneficial	Beneficial	Beneficial
	Availability based on area	Beneficial	Moderate impact	Moderate impact	Moderate impact	High impact	High impact

	Environmental impact	**Solar**	**Solar thermal**	**Wind**	**Biomass**	**Geothermal**	**Hydropower**
	Power reduction after installation	Beneficial	Beneficial	Moderate impact	Negligible	Beneficial	Beneficial
	Dependency on non-renewable energy	Moderate impact	Moderate impact	Moderate impact	Moderate impact	High impact	High impact
	Battery dependency	Moderate impact	Negligible	Negligible	Negligible	Negligible	Negligible
	Installation noise	Moderate impact	Moderate impact	Moderate impact	Moderate impact	High impact	High impact
	Operation noise	Beneficial	Moderate impact	Moderate impact	High impact	High impact	High impact
	Recycling complexity	Negligible	Beneficial	Negligible	Negligible	High impact	High impact
	Chance of accident	Moderate impact	Moderate impact	Moderate impact	Negligible	Negligible	Negligible
	Water for cooling	Moderate impact	Moderate impact	Negligible	Negligible	Negligible	Negligible
	Susceptible to storms	High impact	High impact	Moderate impact	Negligible	Negligible	Negligible
	Communication of species affected	Negligible	Negligible	Moderate impact	Negligible	Negligible	Negligible
	Predator inefficacy	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Collision or entanglement	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Miscellaneous impacts	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Impingement	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible
	Biodiversity	Negligible	Negligible	Moderate impact	Negligible	Negligible	Negligible

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