Halkos, George E.; Zisiadou, Argyro

Article

Energy crisis risk mitigation through Nuclear Power and RES as alternative solutions towards self-sufficiency

Journal of Risk and Financial Management

Provided in Cooperation with:
MDPI – Multidisciplinary Digital Publishing Institute, Basel

Suggested Citation: Halkos, George E.; Zisiadou, Argyro (2023) : Energy crisis risk mitigation through Nuclear Power and RES as alternative solutions towards self-sufficiency, Journal of Risk and Financial Management, ISSN 1911-8074, MDPI, Basel, Vol. 16, Iss. 1, pp. 1-29, https://doi.org/10.3390/jrfm16010045

This Version is available at:
http://hdl.handle.net/10419/275141

Journal of
Risk and Financial Management

MDPI

Review

Energy Crisis Risk Mitigation through Nuclear Power and RES as Alternative Solutions towards Self-Sufficiency

George Halkos * and Argyro Zisiadou

Laboratory of Operations Research, Department of Economics, University of Thessaly, 38333 Volos, Greece
* Correspondence: halkos@econ.uth.gr

Abstract: This paper reviews the case of nuclear energy. Currently, the worldworld is facing one of the greatest energy crises due to the Russo-Ukrainian war. This conflict has lead to limited sources of gas, causing a dramatic decrease in energy supply, leading to emerging energy crisis risks. This is one on the main purposes of reviewing nuclear energy as a possible energy alternative in the future. Apart from presenting the basis of nuclear energy and nuclear reactors, we attempt to compare this source of electricity with other renewable energy forms, such as solar, wind and hydroelectric power. Furthermore, we illustrate the benefits and drawbacks that have been observed regarding nuclear power as well as its contribution to economic growth and the impact it has had on the environment. It has been said that, with the use of nuclear power, air pollution will be reduced because of the elimination of greenhouse gases. However, nuclear power, apart from the final product, generates waste that in this case is radioactive, meaning that the management and disposal techniques are of the utmost importance. Of course, unfortunate events that involved nuclear power do exist and are unfortunately engraved in our memories. Both the nuclear accidents, such as Three Mile Island, Chernobyl and Fukushima, and nuclear weapons usage by military forces, the well-known atomic bombing of Hiroshima and Nagasaki, bring great controversy regarding the adaptation of nuclear power. As is presented in the paper, since the beginning of the new millennium the scheme of energy production and electricity production appears to have changed drastically. By using available data reported by BR, we illustrated that the production of energy and electricity has increased over the last 22 years (2000–2021) due to excessive demand; however, what is more important to mention is the share of both electricity and energy derived from renewable forms such as solar, wind and hydroelectric power. It is shown that more and more countries adopt those sources of energy than did in previous decades. It is crucial to note that it is not the science that causes catastrophic events, but rather the errors of humans.

Keywords: energy crisis risks; nuclear energy; renewable energy; greenhouse gases emissions; nuclear accidents; nuclear weapons; nuclear waste management

JEL Classification: Q01; Q40; Q42; Q52; Q53

check for updates

Citation: Halkos, George, and Argyro Zisiadou. 2023. Energy Crisis Risk Mitigation through Nuclear Power and RES as Alternative Solutions towards Self-Sufficiency. *Journal of Risk and Financial Management* 16: 45. https://doi.org/10.3390/jrfm16010045

Academic Editor: Thanasis Stengos

Received: 12 December 2022
Revised: 6 January 2023
Accepted: 10 January 2023
Published: 11 January 2023

1. Introduction

In present times, humanity is facing one of the most difficult periods in modern history. Over the last years, the quality of the environment has changed dramatically. Halkos and Zisiadou (2019) mention that nature acts independently, and human beings cannot manipulate the results of this independency. Nevertheless, this statement refers to the natural phenomena that occur on Earth, such as earthquakes, volcanic eruptions, tsunamis, etc., so even if we exclude human activity from the scheme, it is logical that the Earth will continuously transform. However, the impact of human activity should always be taken into consideration because it causes significant, and sometimes disastrous, alterations. It has been said that technology can either be a blessing or a curse depending on the way it is used (Halkos and Zisiadou 2020a).

Since the advent of the Industrial Revolution, there has been a sharp increase in the demand for electricity, and as a result the massive production of electricity by non-renewable sources. Because of the use of fossil fuels as main production raw materials, leading to enormous greenhouse gases emissions, environmental quality has been degraded. Greenhouse gases have caused the increase in the temperature of the terrestrial atmosphere, which is also known as global warming, and combined with air pollution caused due to increased industrialization, the Earth is facing the phenomenon of climate change. The situation is getting worse year by year due to the fact that there is a global annual increase in energy demand. In order to generate these amounts of energy needed, we should either increase the production of electricity using fossil fuels, which will then increase the greenhouse gases emissions and air pollution in general (Barros and Managi 2016), or we should promote more sustainable forms of energy. Solar, wind, hydroelectric and nuclear power can generate electricity while at the same time reducing greenhouse gases and carbon dioxide emissions. Renewable sources of energy (solar power, wind power and hydroelectric power) characterized by unpredictable power production (Basit et al. 2020) do not totally fulfill the criteria of sufficient productivity (Mastrocinque et al. 2020; Mourmouris and Potolias 2013) due to the fact that they are affected by the acts of nature. Nuclear power, on the other hand, may be a suitable option for power production replacement.

Another problem that the worldEarth is currently facing is the energy crisis that has resulted from the Russo-Ukrainian war. Following Alam et al. (2022) and Prohorovs's (2022) work regarding the Russo-Ukrainian war, we aim to underline possible alternatives that can be used to address the global energy crisis. Researchers emphasize that the existing war has pushed the global economy to a crucial point (Alam et al. 2022; Prohorovs 2022), where increased inflation rates observed globally as well as the instability of commodity markets and the increased uncertainty indicate a not so prosperous economic future. The limited fossil fuels that are available in nature, together with the energy embargo of Russia have led to a sharp increase in prices, with consequences to the global economy through inflation. Prohorovs (2022) examined the consequences for European countries' businesses and economies and highlighted that most countries need to expedite their development of sufficiency with regard to enerty resources. This appears to be a powerful factor that brought nuclear power into discussion as an attempt to ensure that there is going to be sufficient energy worldfor the Earth, inthe following years, and at the same time provide sustainable solutions for the next generations. What is important to examine, however, is whether nuclear energy appears to be trustable by nations around the worldworld as a source of energy production. For that reason, we are going to investigate, using reported data, whether nuclear energy has been adopted by more countries over the last two decades. Moreover, based on the same dataset, we are going to address the questions regarding renewable forms of energy and electricity production. A main question raised about renewables is if they are assumed to be a possible extension of energy production. Do nations trust and adopt those sources in order to cover a part of the needed energy and electricity production? Do they increase their share of global production?

The structure of the paper is as follows following: Section 2.1 provides a literature review on nuclear energy and specifically the reactors, while Section 2.2 presents the other renewable energy forms. Section 2.3 underlines the advantages and disadvantages of nuclear power, while Section 2.4 draws attention to the economic growth and environmental impact that have resulted from it. The following section provides information regarding nuclear waste management and disposal. Sections 2.6 and 2.7 review the most known nuclear accidents and military attacks using nuclear weapons. Section 3 illustrates the current conditions regarding the global energy mix and electricity since 2000. Finally, the last section concludes with significant statements regarding the topics analyzed above.

2. Literature Review

2.1. Nuclear Energy

Over the last several years, more and more nuclear power reactors have been constructed in an attempt to increase the nuclear energy produced globally. Many reasons are hidden behind these decisions, but energy sufficiency and climate change appear to be the most important. The first nuclear power plants in the world started operating in the 1950s. Since then, their expansion has been noticeable. Deutch et al. (2003), underline that during this time, 44 new nuclear power plants were under construction in 12 different countries, with most of the constructions being in China, India, Korea and Russia. As for the USA, at that point there was no plan for additional nuclear power plant construction. A fewew years later, Ozcan et al. (2016) showed that new power plants were being constructed. At that period of time, the number of reactors under construction increased to 59, with four more countries entering into their construction. Akyuz (2017), emphasizes that, to date, 31 countries around the world have nuclear power plants, with a total of 447 nuclear reactors which annually produce about 17% of the world's electricity (da Mata et al. 2017). Elliott (2016) highlights that the net nuclear power capacity equals to 392 gigawatts (GW).

Topal-Namli and Namli (2014) provide information regarding the percentage of nuclear power of a portion of total energy for some countries. More specifically, 75% of the electricity used in France derives from nuclear power, while other european countries such as Belgium, the Czech Republic, Hungary, Slovakia, Slovenia, Sweden, Switzerland and Ukraine depend on nuclear power for up to 1/3 of their total consumption. Additionally, more than 30% of the electricity used in South Korea, Bulgaria and Finland derives from nuclear power. High dependency on nuclear power is also reported in USA, United Kingdom, Spain and Russia, with nuclear power consumption reaching almost the 20% of the total energy expenditures. Japan, which is known for its nuclear facilities, derives than 25% of its annual electricity supply from nuclear power. Lastly, countries such as Italy and Denmark that do not have any nuclear power plants satisfy approximately 10% of their electricity demand through nuclear power.

The great concern that has been raised regarding the phenomenon of climate change in recent years has forced scientists and policy makers around the world to explore new forms of energy production. What makes nuclear power a great candidate is the fact that, unlike oil and gas, the raw materials that are used in nuclear power plants, such as uranium, are available in large quantities in nature, which can ensure adequate energy production in the present, but also in the long-run, maintaining the viability of this form of energy (Jewell 2011; NEA 2008; Macfarlane and Miller 2007). Moreover, as da da Mata et al. (2017) mention, nuclear energy tends to be more competitive compared to other forms of energy, due to the fact that it produces a large amount of electric power, with low operational costs and minimum polluting gas emissions, which mainly occur during material and waste transport, while at the same time providing great financial returns. Additionally, Brook et al. (2014), indicate that nuclear fission has the lowest environmental impact, especially because of limited gas emissions, a statement which classifies nuclear energy among the cleanest sources of power. This statement, together with the increasing concern regarding climate change, has forced governments and policy makers to rethink the possibility of launching national nuclear power programs (Adamantiades and Kessides 2009; Nuttall 2005; Sauga 2008).

Reactors

Vaillancourt et al. (2008) released a thorough analysis regarding the reactors that are currently in use worldwide. Based on their analysis, there are five different types of reactors available, from which four types of reactors produce electricity with nuclear fission using uranium as a fuel, while only one of the reactor types produces electricity with nuclear fusion using tritium, which is produced from lithium, as a fuel. More specifically, the five available reactor types are: (a) Light water reactors (LWR), (b) Advanced light water reactors (A-LWR), (c) Pressurized heavy water reactors (PHWR), (d) High-temperature gas-cooled reactors, and (e) Fusion power reactors.

More analytically, these five types of reactors are divided into those categories based on the technology used to produce electricity, as well as the primary fuel they are using during the main procedure. Starting from the first type of reactor, the Light water reactor (LWR), it is important to mention that it is a second-generation reactor and based on the NEA (Nuclear Energy Agency) (NEA 2005), 90% of the total reactors in use globally belong to this specific type of reactor. The two subtypes of Light water reactors are the pressurized water reactors (PWR) and the boiling water reactors (BWR). The OECD (Organization for Economic Co-operation and Development) (OECD 2001) mentions that the development of the Light water reactors took place in the USA and FSU (Former Soviet Union). Vaillancourt et al. (2008) explain that LWR tend to be replaced by newer technologies and more advanced reactors when their useful life cycle expires.

The second most common type of reactor worldwide is the Advanced light water reactor (A-LWR), which is described as an upgrade of the LWR. These third-generation reactors (Hamacher and Sheffield 2004) appear to be the upgraded version of LWR in terms of lower investment and operational costs, a higher availability factor, and a longer lifetime, and as mentioned above they are part of the LWR replacement process. It is interesting to note that 80% of the under-construction reactors globally are of this type (NEA 2005). On the contrary, a not so selected reactor is the Pressurized heavy water reactor. As EIA (2006) illustrates, the PHWR is designed by Atomic Energy of Canada Ltd., and includes amongst others the CANDU (Canada Deuterium Uranium) reactor. However, Vaillancourt et al. mention that only 5% of the reactors in use globally belong to this category, and only constitute 15% of the under-construction reactors. Moreover, apart from Canada, which is their country of origin, five more countries have adopted these types of reactors, including Argentina, China, India, Romania and South Korea. India and Romania are currently constructing more of the PHWR (EIA 2006).

The next two types of reactors, the High-temperature gas-cooled reactor and the Fusion power reactor, are under development, with the expectation that they will be released around 2030 and 2050, respectively. More specifically, the High-temperature gas-cooled reactor is characterized as the fourth-generation reactor, is developed in United Kingdom, and its main difference, compared to the previous three reactors, is the fact that it uses helium as a coolant element instead of water, and is planned for construction in South Africa (OECD 2001). Last is the Fusion power reactor, which is an ITER project, and it is also currently under development. Researchers support the belief that this type of reactor will be available in 2050 based on estimates (Fiore 2006; Hamacher and Sheffield 2004; Tokimatsu et al. 2003). Based on Fiore (2006), the factor that establishes the Fusion power reactor as the best possible choice is its difference with regard to the type of fuel used. As already mentioned, the first four reactors use uranium as a fuel, while the fifth reactor will use lithium, an element for which reserves are reported to be unlimited and, indeed, will be available for a thousand years (Vaillancourt et al. 2008; Fiore 2006). What is crucial to mention is that there are more types of reactors such as the Small Modular Reactor (SMR), Gen-IV reactors and others; however, the five reactors analyzed above by Vaillancourt et al. (2008) are assumed to be the most common globally. Reviews regarding the Gen-IV reactors and the status of their operations has been conducted by many researchers focused on the nuclear energy (Lorusso et al. 2018; Kim 2013; Murty and Charit 2008; Driscoll and Hejzlar 2005). Similarly, regarding the operation and progress of SMR and whether this type of reactor can be the cheapest and safest choice of nuclear energy production as a result the possible future of energy globally has been discussed by numerous scientists (Kumar et al. 2021; Rowinski et al. 2015; Cooper 2014; Liu and Fan 2014; Vujić et al. 2012; Wang et al. 2011).

2.2. Renewable Energy Sources

Renewable energy forms have gained great public attention over the last years, possibly due to the opposition of institutions to nuclear energy and with regard to their efforts in reducing GHG emissions (Hossain et al. 2022; Immonen and Kopsakangas-Savolainen 2022;

Zhao et al. 2022; Brook et al. 2014). As has already been mentioned, there is a great concern in the circles of environmental and social scientists due to the sharp increase of reported Greenhouse Gases (GHG) emissions and the adverse outcomes leading to climate change. In an attempt to reduce GHG, a great majority of countries are trying to adopt alternate forms of energy. As Brook et al. (2014) underline in their paper, institutions and public opinion appear to be against nuclear energy production because of the belief that this form of energy is assumed to be unsustainable, uneconomic and unsafe, while it increases the risk of nuclear weapons production and use. Renewable energy appears to be one of the main options countries have, with some nations announcing that their main purpose is to substitute, if not all, at least the majority of their electricity production by using renewables (Brook et al. 2014). Another reason that made people turn their focus to renewables is the realization that there is a limited availability of fossil fuels, meaning that in the future they will not be able satisfy the required energy demands. Thus, if we exclude the energy produced by fossil fuels and/or nuclear energy, the alternatives we have are (a) solar power, (b) wind power, (c) hydroelectric power, (d) geothermal power, and (e) biomass. Regarding the sustainability of renewable energy, it is crucial to mention that a source can be assumed as sustainable only if it can provide a great amount of energy in the long-run, is capable of fulfilling daily demands, without depriving future generations, while at the same time being reliable, safe and environmentally friendly, and of course economically feasible. Therefore, the origin of renewable energy types (sunlight, wind, water etc.) sets limitations on the availability of energy production due to weather phenomena, leading to the belief that they may not be able to be characterized as sustainable (Brook et al. 2014). However, what is important to mention is that due to the development of technology, more and more solutions have been found in order to solve the problems that are occurring. In other words, scientists try to advance the technology with regard to the energy storage. Alkhalidi et al. (2022), Kebede et al. (2022), and Aneke and Wang (2016) have made a thorough analysis of all available energy storage technologies that are currently available around the world and may be assumed as a solution to the renewable source projects by improving the efficiency of energy production as well as the energy storage applications.

As Aneke and Wang (2016) mention, there are two different types of energy storage technologies, the electrical and the thermal, with subtypes such as mechanical energy storage (MES), chemical energy storage (CES), electrochemical energy storage, superconducting magnetic energy storage (SMES), cryogenic energy storage, sensible heat storage, latent heat storage, thermochemical heat storage, and possibly even more subtypes of energy storage technologies. The importance of energy storage technologies has also been described by Rahman et al. (2020), who also reported the challenges attached to the stability and reliability of renewables with regard to sufficient energy supplies. Through an overview of energy storage technologies, Rahman et al. (2020) have concluded that energy storage systems may provide a solution to the uncertainty regarding the sufficiency of energy produced and stored by renewable sources. Having these solutions in mind, more nations will be able to adopt the renewable forms of energy production, and hopefully in the future the environmental impact of energy production will be reduced.

2.2.1. Solar Power

One of the most common forms of renewable energy is solar. It is based on solar radiation, which is captured through photovoltaic cells (PV), which, by heating water, produce electricity. As da Mata et al. (2017) underline in their paper, the photovoltaic flat plates can be installed either on buildings or special structures. In recent years there has been a significant increase in the number of sales of photovoltaic modules, which therefore led to a decrease in their price. Although there was a significant price drop, the average cost per photovoltaic unit is still high, sometimes even estimated at 10 times the cost of more common sources of electricity. This drawback may be a limitation to the expansion of the solar power industry.

2.2.2. Wind Power

Another form of renewable energy that has gained increasing attention in recent years is wind power. According to da Mata et al. (2017) there has been a recorded annual increase of about 20% over the last 5 years. Brook et al. (2014) emphasize that fact that wind power is one of the most ancient types of power generation. Over the centuries, wind provided great benefits to humanity for everyday activities such as wheat grinding, wood sawing and water pumping. Moreover, for many centuries, travelling around the world was only possible due to wind used in sailing, making transportation possible. One of the main drawbacks of wind power, however, is the limited availability. Electricity, or power in general, cannot be produced when there is no wind. In previous centuries, in there was no wind for a day or two, transportation was likely to be delayed. However, in current times, if there is no wind, the electricity already produced may not be able to cover the daily power demands.

2.2.3. Hydroelectric Power

Another renewable form of energy da Mata et al. (2017) illustrate is hydroelectric power, which is also believed to be an ancient type of energy production. The generation of hydroelectric power can be achieved through the use of the force of water, usually taking the form of rivers and dams. In contrast to solar and wind power, which are not fully reliable due to the possible lack of sunlight and/or wind, hydroelectric power appears to be a more stable source of energy. da Mata et al. (2017) underline the fact that by 2015, 16% of global electricity was provided by hydroelectric power, with some countries depending mainly on it as their main energy source. Characteristic examples are Norway, with 99% of the country's electric consumption produced by hydroelectric power, while Canada, Switzerland and Sweden have usage percentages of 58%, 55% and 45%, respectively.

Obviously, this type of energy does have its own disadvantages. The first and most serious disadvantage is the fact that in order to have a sufficient, continuous water supply, there is a need to construct dams, which has been shown to cause significant environmental damage to the surrounding ecosystem. The other noticeable disadvantage is a possible drought occurrence, which will decrease the volume of the available water, a phenomenon which is currently more visible due to climate change and global warming (da Mata et al. 2017).

2.2.4. Geothermal Power

Geothermal power, which is recognized as a renewable energy resource (Rybach 2003) is the energy created by the heat of the Earth, as Kagel et al. (2005) have mentioned. Kagel et al. (2005) analyzed the geothermal energy produced by United States since 1960 and pointed out that due to the fact that during geothermal energy production no fossil fuels are used, there are no harmful air emissions that will burden the environment. Moreover, they clarify that although sulfur dioxide is not directly emitted during the energy production through geothermal power plants, the hydrogen sulfide is transformed into sulfur dioxide and sulfuric acid when released to the atmosphere. Rybach (2003), following the Kyoto Protocol suggestions, emphasizes that although all different types of energy production may have an impact on the environment, the technology used during the energy production is what affects the level of encumbrance. As for geothermal power production, based on figures presented by Rybach (2003), coal, oil, and gas have higher GHG emissions, while hydroelectric, solar and wind have lower GHG emissions. These indications characterize geothermal as an attractive alternative solution for GHG emissions reduction. Based on Kagel et al. (2005), due to the fact that the Earth's interior temperature is expected to remain high for billions of years, geothermal energy can be assumed to be a sustainable alternative for a long time.

Regarding the main disadvantages of geothermal energy production, Bagher et al. (2014) underline that this source of energy cannot be available everywhere in the world, while at the same time the power plant sites are not close to the distribution areas. Moreover, when analyzing the investment cost, the steam power plant cost is relatively high, and it is not certain whether a depreciation of such an investment will be achieved.

2.2.5. Biomass

Another renewable energy source alternative is biomass, which is assumed to be a great source of energy that can contribute to the increased energy demands of the modern society (Bridgwater 2006). Compared to other renewable energy sources, biomass is the one that produces the most emissions during energy generation that burdens the environment with gases (HCI, SO_2, HF, HCN, NOx and CO), particulates (PM 2.5, PM 10), as well as toxins that, if not handled properly, may become hazardous (Song and Hall 2020). A great disadvantage of biomass as described by Vassilev et al. (2015) is the high investment cost required for a biomass power plant installation, thus increasing the risk of non-depreciation, as is the case with geothermal energy.

2.3. Advantages & Disadvantages of Nuclear Energy

Living in the real world, none of the decisions or actions human beings choose is perfect. The same idea is observed in terms of nuclear energy as well. When examining the option of adopting a new process, we have to thoroughly comprehend all different aspects, positive and negative, that may appear, so as to weight them properly on our final decision. For that reason, before we reach any conclusions about nuclear energy, we need to evaluate both the advantages and disadvantages that exist. As has already been mentioned above, 90% of the in-use reactors belong to the LWR type. Based on Schiermeier et al. (2008), this specific type of reactor can produce electricity with a cost varying between $0.025 and $0.07 USD per kilowatt-hour, with the fluctuation appearing due to the design and/or requirements of each reactor. The equivalent cost per kilowatt-hour when using natural gas is approximately $0.05 USD. The low cost of production is mainly affected by the low cost of raw material (Temurçin and Aliağaoğlu 2003). A similar comparison between nuclear energy and production cost was also made by Akyuz (2017) and Aras (2013). That factor highlighted the fact that nuclear energy can sometimes be an cheaper solution compared to the known and excessively used methods.

Following the shame concept, other researchers have estimated the cost per MWh both for nuclear energy generation and renewable energy generation. More specifically, Korkmaz and Önöz (2022) provide evidence that the average cost system cost regarding the nuclear energy scenario equals to $64 USD per MWh (giving a $0.064 USD per KWh), while the renewable energy scenario provides an average system cost of $62.3 USD per MWh (giving a $0.0623 USD per KWh). As they mention, the reported costs are the levelized costs of electricity generation (LCOE). Barthelmie and Pryor (2021) reported the LCOE of wind energy generation and underlined that regarding the onshore wind en-ergy LCOE is almost $40 USD per MWh in U.S.A and Europe (giving a $0.04 USD per KWh) and almost $60 USD per MWh in Asia (giving a $0.06 USD per KWh) while the offshore LCOE is higher compared to the onshore LCOE and ranges between $106-$171 USD per MWh in specific countries (giving a $0.106-$0.171 USD per MWh). The results provides by Korkmaz and Önöz (2022) and Barthelmie and Pryor (2021) are comparable with those provides by Schiermeier et al. (2008). Hansen (2019) followed a similar ap-proach in reporting LCOE of many different electricity generation sources, however, the results are presented in €. As Hansen (2019) mentions, onshore wind power has the lowest LCOE, which equals to €34 per MWh (€0.034 per KWh), followed by coal power plants with LCOE equal to €39 per MWh (€0.039 per KWh), followed by large-scale hydro-power with a LCOE equal to €40 per MWh (€0.04 per KWh) and small-scale hydro-power with a LCOE equal to €45 per MWh (€0.045 per KWh). Combined Circle Gas Turbines provide a LCOE equal to €58 per MWh (€0.058) while the offshore wind power gives a LCOE equal to €66 per MWh (€0.066 per KWh) and nuclear power generations provides a LCOE equal to €69 per MWh (€0.069 per KWh). Similarly, large-scale photovoltaics (solar power) report a LCOE equal to €72 per MWh (€0.072 per KWh) while small-scale photovoltaics report a LCOE equal to

€104 per MWh (€0.104 per KWh). Finally, biomass power plants provide a LCOE equal to €88 per MWh (€0.088 per KWh).

If we compare nuclear energy to other renewable energy forms such as solar power and/or wind power, it is proven that nuclear energy is assumed to be a sustainable source due to the fact that it fulfills all required criteria. Renewable energy forms depend on meteorological conditions, as we have already stated. Those conditions may reduce or even eliminate electricity production using solar, wind or hydroelectric power. Nuclear power, on the other hand, is not affected by similar conditions, leading the supporters of the NNPs to emphasize that sustainability is one of the main advantages of nuclear energy (Coskun and Tanriover 2016). Researchers (Akyuz 2017; Kok and Benli 2017; Kurt 2014; Aras 2013) who have analyzed Turkey's case regarding its dependence in oil and natural gas imports conclude that the country is heavily dependent of those imports, and even a slight decrease on those imports may have a huge negative impact to the electrical situation of the entire nation. If establishing nuclear power plants in Turkey, they firmly believe that the risk of electrical insufficiency is drastically reduced. Moreover, apart from the risk of sufficient supply, Topal-Namli and Namli (2014) state that Turkey will also be able to reduce energy expenditures.

Another great advantage supporters of NPPs underline is the longevity of the main equipment of the nuclear power plants, the reactors. More specifically, the initial reactor designs were guaranteeing a 40-year operational lifespan of the reactors used; however, the evolution of technology extends their operational ability up to 80 years (Ozcan et al. 2016). This is the strongest and most alluring benefit that nuclear energy has to offer. Contrary to fossil fuels, which are the main producers of greenhouse gas emissions, causing global warming and climate change, nuclear power plants do not emit greenhouse gases during the process of electricity production (Akyuz 2017; Ilhan et al. 2010; Sirin 2010; Erdogdu 2007).

Although nuclear energy and nuclear power plants have numerous benefits, both for the economy and the environment that have already been mentioned, their opponents express their firm dissatisfaction based on their significant drawbacks (Akyuz 2017). The initial statement that is raised by Gunay and Iseri (2017) is related to the insufficient and ineffective regulations that many countries have regarding nuclear energy. More specifically, many countries around the world, such as Turkey, do not have sufficient and laws and regulations, nor highly-trained operators, that are required to observe and guarantee nuclear safety. This factor significantly increases the risk of a potential industrial accident. In order to tackle this possibility, the governments of these countries should establish a comprehensive nuclear energy plan in an attempt to reduce current uncertainty (Topal-Namli and Namli 2014).

Despite the fact that Schiermeier et al. (2008), underline the low cost of production compared to fossil fuels, Akyuz (2017), states that nuclear energy can be assumed to be a very costly energy source due to the excessive investment cost. This is a critical reason for Turkey's NPP cancellations. Another factor that increases the operational costs of NPPs is nuclear waste management, which requires substantial standard techniques and equipment (Ozcan et al. 2016). Regarding waste management and disposal, this will be thoroughly described in a following Section (see Section 2.5), Cohen (1983) and Sirin (2010), emphasize the great danger that lies beneath waste management and disposal. Nuclear power plants create toxic, radioactive and extremely hazardous waste that remains hazardous for sometimes even hundreds of thousands of years. Cohen (1983) specifically mentions that 99% of their contaminants remain on materials even after 600 years. Even if we dispose of them in the burying zones, there is an unacceptable level of risk both for people and the environment.

Regarding spent fuel and its recycling process, apart from being costly, it increases the possibility of nuclear theft risk. Due to the fact that nuclear weapons can be created from nuclear energy fuel residuals, the proliferation danger is increased. (Sokolski 2010). Moreover, nuclear power plants can produce plutonium for military purposes (Akcay 2009), and although most countries of the world have signed the Non-Proliferation Treaty (see

Section 2.7.3), no one can ensure that they will not create nuclear bombs which will disturb worldwide peace.

History shows that the next three drawbacks sometimes may be connected with each other. Topal-Namli and Namli (2014) state that nuclear power plant locations are chosen based on their surroundings, due to the fact that those facilities have need immediate access to water for cooling purposes. Therefore, seaside, riverside and lakeside areas are the perfect location for the construction of a nuclear power plant. On the other hand, based on recorded events, nuclear power plants are vulnerable to natural phenomena, such as earthquakes and tsunamis. The most well-known case is the Fukushima Daiichi Nuclear Power Plant case (see Section 2.6.3), a facility which was built close to the coast in order to have access to water for cooling purposes, and a tsunami caused the cooling system shutdown, leading to the greatest nuclear disaster of the new millennium. The last disadvantage mentioned by Akyuz (2015) is the risk of nuclear accidents in general. In spite of not being a frequent phenomenon, with only 33 accidents and incidents reported to date, the disastrous impact of such events is devastating. The worst case in history was the Chernobyl disaster (see Section 2.6.2).

2.4. Economic Growth and Environmental Impact

Another aspect that authorities have to weigh for a possible expansion of nuclear energy is the economic growth that will accrue to each nation along with the range of environmental impacts. An in-depth study by Apergis and Payne (2010) examined the linkage between nuclear energy consumption and economic growth for a period of 26 years (1980–2005) and included 16 countries. The factor that triggered the researches to examine this linkage was the highly volatile price of oil and gas, including the fact that a great number of countries depend on the imports of such products, as well as the excessive greenhouse gases emissions produced from fossil fuels that have a negative impact on the environment. As stated by Fiore (2006) as well as Toth and Rogner (2006), nuclear energy may be be highly significant when used in regions where energy demand growth is rapid if we consider that the scientific society has announced that fossil fuel reserves will not be sufficient to cover the global energy demand sometime in the near future.

One of the most well-known environmental hypotheses that provides a linkage between economic growth and environmental pollution is the Environmental Kuznets Curve (EKC) hypothesis, which graphically is presented as an inverted U-shaped relationship (Iwata Hiroki and Samreth 2010). Based on this theory, during to the initial stages of economic growth and increasing incomes, environmental pollution and natural resource degradation is observed, while after a certain point of increasing income, an additional unit of income leads to a reduction in environmental pollution. A number of scientists have focused their research on CO_2 emissions and energy consumption, mainly nuclear and renewable energy. Irfan and Shaw (2017) state that renewable energy leads to carbon emissions reduction, while non-renewable energy leads to an increase in it. Apergis and Payne (2010) underline that renewable energy consumption does not have a decreasing impact on carbon emissions, a similar finding to the Menyah and Wolde-Rufael (2010) study. Forsberg (2009) and Heal (2009) emphasize that this reduction may not have been achieved due to the lack of adequate storage technology for renewable energy; however, in the long-run renewable energy technologies appear to improve environmental quality. Regarding the environmental impact that s connected to the nuclear energy production, it is crucial to mention that uranium mining may increase the risk of environmental danger. The good news, however, is that due to the new technology in nuclear reactors, the quantity of uranium needed for nuclear energy production will sharply decrease. In that way, the volume of waste that needs to be managed and isolated, as well as radioactivity hazards, will be drastically reduced (Brook et al. 2014).

Franco et al. (2017) undertook a study in India for the period 1901–2011 and their findings indicate that although urbanization leads to economic growth and improvements in quality of life, carbon dioxide emissions are significantly increased due to the higher levels of energy consumption. Many researchers (Shafiei and Salim 2014; Jebli Mehdi Ben and Ozturk 2016), when examining the CO_2 emissions in OECD countries, separate the energy variable into two subcategories, renewable and non-renewable, indicating that non-renewable energy increases CO_2 emissions, while renewable energy decreases CO_2 emissions in these countries. Lastly, Al-Mulali et al. (2015) examine the Vietnam case and observe that although non-renewable energy consumption increases CO_2 emissions, renewable energy consumption has no effect on carbon dioxide emissions. On the other hand, Al-Mulali et al. (2016), examine the Kenya case (1980–2012) and find that renewable energy consumption reduces carbon dioxide emissions, while non-renewable energy consumption and urbanization increase carbon dioxide emissions, and as a result, environmental pollution.

Paramati et al. (2017), on their econometric analysis over the period 1990 to 2012, regarding developing countries, state that renewable energy consumption can positively affect economic growth, as well as the quality of the environment. Menyah and Wolde-Rufael (2010), underline the fact that the economic impact of the global warming phenomenon can be incredibly costly and lead to a 25% decline of global GDP (Gross Domestic Product). If we take into consideration the energy crisis many countries will face due to the fact that energy imports will be declined (Hedenus et al. 2010), we can imagine the great decrease that will be reported in the global GDP. It is crucial to understand that the phenomenon of global warming is not only an environmental disaster, but also a huge threat to the global economy (Adamantiades and Kessides 2009; DeCanio 2009; Reddy and Assenza 2009).

Omri et al. (2015) conducted an in-depth study in order to examine the causality between nuclear and renewable energy consumption and economic growth. They proposed four hypotheses regarding causality, the growth hypothesis, the conservation hypothesis, the neutrality hypothesis and the feedback hypothesis. The growth hypothesis indicates that there is a unidirectional causal relationship running from energy consumption to economic growth. The conservation hypothesis indicates that it is assumed to be a unidirectional causality running from economic growth to energy consumption. The neutrality hypothesis indicates that there is no causality between energy consumption and economic growth, and the feedback hypothesis posits that there is a bi-directional causality between energy consumption and economic growth. Regarding nuclear energy, the growth hypothesis is accepted for Belgium and Spain, while the conservation hypothesis is accepted for Bulgaria, Canada, The Netherlands and Sweden. The neutrality hypothesis is accepted for Finland, Hungary, India, Japan, Switzerland and the U.K. Finally, the feedback hypothesis is accepted for Argentina, Brazil, France, Pakistan, and the United States (Omri et al. 2015). Similarly, regarding renewable energy, the growth hypothesis is accepted for Hungary, India, Japan, The Netherlands and Sweden, while the conservation hypothesis is accepted for Argentina, Spain, and Switzerland. The neutrality hypothesis is accepted for Brazil and Finland. Finally, the feedback hypothesis is accepted for Belgium, Bulgaria, Canada, France, Pakistan and the United States (Omri et al. 2015).

2.5. Waste Management & Disposal

As we have already mentioned in Section 2.1, nuclear energy production, like any other type of production, apart from the final product, also produces waste. However, not all waste is the same. In the case of nuclear waste, we should always have in mind the statement that Corkhill and Hyatt (2018) made regarding the high radioactivity of fission products and actinides. In other words, the most crucial process after power generation is the procedure of waste management and disposal. These radioactive materials need to be treated and stored properly so that they will not have a hazardous effect on humans and the environment (Corkhill and Hyatt 2018; Keeney and Winterfeldt 1994). As is well-known, the level of radioactivity declines over the years. Nevertheless, this is a lengthy process that in some cases may exceed hundreds of thousands of years. The two terms used in order to describe the period of time that is needed for nuclear waste to reduce its radioactivity are half-life and hazardous life, with half-life being the period of time that is needed to decay half of the element's radioactivity, while hazardous life refers to the period of time that is needed to decay to a thousandth or millionth of an element's original amount of radioactivity, and this amount is usually is 10 or 20 half-lives.

For instance, the half-life of Tritium is 12 years, while its hazardous life is equal to 120–240 years. Similarly, the half-life of Strontium-90 equals 28 years, while its hazardous life equals to 280–560 years. A great example is Nickel-25, which has a half-life equal to 76,000 years, and a hazardous life equal to 760,000–1,520,000 years. Having this a priori information in mind, it is essential to mention that is not only important how the waste is treated after nuclear power production, but it is also crucial to find suitable methods and storage for these radioactive elements in the long-run, and of course avoid the corrosion of the storage material before the end of the hazardous life, otherwise the radioactivity will be spread to the environment. This is the main reason why nuclear waste management is significantly more expensive compared to nuclear energy production.

The four main nuclear waste types are the following: Spent Nuclear Fuel (SNF), High-Level Waste (HLW), Intermediate-Level Waste (ILW) and Low-Level Waste (LLW). Each type of waste has a different process of management and disposal. Before we move forward to the waste management and disposal processes, it is important to clarify the differences between these types of waste. The nuclear fuel used in a reactor in order to produce electricity is uranium oxide. Since uranium oxide has undergone fission, it is removed from the reactor and is called Spent Nuclear Fuel (Corkhill and Hyatt 2018) and is assumed to be the most controversial type of nuclear waste (Ramana 2018; Flynn et al. 1995), due to the fact that it continuously transforms and includes high levels of radioactivity. If a person was exposed to such level of radioactivity, they would absorb a lethal dose in less than a minute. The most common method of SNF management and disposal is to cool the fuel for several years (2–5 years) under water in special engineered cooling ponds and then stored in containers and transferred to long-term storage locations. Moving forward, nuclear waste that includes concentrations of radionuclides, which increase radiogenic self-heating, are known as high-level waste, and contain substantial levels of radioactivity. Similar to the high-level waste, the intermediate-level wastes contain significant levels of radioactivity, but it is lower compared to high-level waste, and still requires caution with regard to the waste management and disposal process. Last are the low-level wastes which cannot generate heat, have low levels of radioactivity, and do not require any special consideration with regard to the management process (Corkhill and Hyatt 2018). Below, we will analyze all possible methods that can be used in the process of waste management as well as waste disposal.

Waste immobilization is a waste management technique that is divided into two types based on the materials used. The purpose of waste immobilization is to ensure that the radioactive materials will be handled, transported and stored safely, minimizing the potential risks to human health and the environmental. In other words, the material should remain stable during the transport and storage, as well as remain stable under required temperature ranges and radiation fields, and finally, durable and not easily dissolvable under conditions of long-term storage and disposal. Vitrification using borosilicate glass is an attractive immobilization technique, especially for high-level wastes. Not only can borosilicate glass be used during this process, but other kinds of glass, such as aluminophosphate glass, are commonly used in Russia (Corkhill and Hyatt 2018; Stefanovsky et al. 2004; Yim and Linga Murty 2000; Weber et al. 1997; Lutze 1988). The second waste immobilization technique is cementation. In contrast to borosilicate glass, cementation is preferable for intermediate-level waste. In this process, the radioactive waste is simply surrounded or encapsulated by a wet cement paste which gradually turns into a hard cement block. A great advantage of this process is the fact that cement is a low-cost material which can be simply processed and handled. (Corkhill and Hyatt 2018; Yim and Linga Murty 2000).

Another option for waste management that has been proposed was to remove nuclear waste from the Earth and to store it in space. A more suitable option is assumed to be the removal of nuclear waste from the surface of the Earth. The reason behind this is that the upper layers of the surface are exposed to environmental risks, such as climate change, tectonic plate movements, and of course human intrusion. Thus, geological disposal of high-level waste is proposed, basically by burying the wastes several hundreds of meters or more below ground into special containers. This concept is suitable for the long-term storage of nuclear waste (Corkhill and Hyatt 2018). In order to successfully dispose of nuclear waste using this proposed method, it is crucial to follow the proposed principle so as to maintain safety. This concept is known as the multi-barrier concept and indicates that, first of all, specially engineered multi-layer barriers will contain the nuclear waste until the moment that the majority of the radioactivity will be decayed. Secondly, the host geology will successfully isolate the barrier from the biosphere so as to reduce the likelihood of human intrusion and, finally, the location of the storage facility will be several hundreds of meters below ground and will ensure long transport pathways to decay any significant migration of radionuclides from the waste to the biosphere (Corkhill and Hyatt 2018). Based on Hench et al. (1986), an engineered waste package is a seven-layer container consisting of (a) alkali borosilicate glass or titanate based polyphase serving as a host matrix for the high-level waste, (b) a metal canister, usually stainless steel surrounding the glass compartment, (c) a metallic overpack such as mild steel ductile iron, pure titanium, titanium alloy, or nickel alloy, (d) a sleeve which is used in order to assure the clearance for the package, (e) the backfill of a material contained between the other engineered waste package components and the host rock, (f) a buffer, which is a material used to facilitate the conditioning of the ground water, and (g) filler, which can be any material used to fill the space between the other components of the waste package.

2.6. Nuclear Accidents

The majority of individuals who oppose nuclear power plants, and nuclear energy in general, are probably adversely affected by the worst nuclear disasters of the century. These events have raised great public attention and obvious negative publicity. However, it is crucial to mention that science, when used properly and with the required respect, is not disastrous. Irrational decisions, overuse and/or reckless use or other external factors may lead to catastrophic results. Three main events will be described below, where different initial factors led to environmental hazards. However, one of the initial nuclear accidents that occurred was during a fission reaction by Slotin and his colleagues in 1946 leading to Slotin's death and giving us the knowledge regarding the negative results of exposure to radiation. More specifically, on 21 May 1946, at Los Alamos Scientific Laboratory, a nuclear experiment was conducted by Louis Slotin and seven other laboratory members (McLaughlin et al. 2000). Based on McLaughlin et al. (2000), two of the members, Louis Slotin and Alvin Graves, were directly involved in the experiment, while the other six individuals were observing the demonstration. Malenfant (1996), who reported four similar laboratory accidents between 1945 and 1946, reported detailed information regarding the LA-1 accident during Slotin's demonstration, and mentioned that the eight personnel were exposed to excessive levels of radiation. More specifically, Oettingen (2018) underlined that Slotin was exposed to 2100 rem, leading to his death nine days after the occurrence of the accident, while Graves received 360 rem, and recovered several weeks after the experiment. Regarding the six observers, Hempelman et al. (1979) mentioned that they were exposed to lower levels of radiation, and thus there were no major impacts on their health. Malenfant (1996) indicated that this accident, as well as similar accidents to Slotin's, have a great significance because they provide information about the undesirable effects when potentially hazardous experiments were conducted without the appropriate planning, preparation and safety measures. In other words, Slotin's accidents and similar accidents of the past provided us with the knowledge that nuclear energy can be hazardous and disastrous if used without respect for safety measures. This information was not always kept in mind during operations in nuclear power plants. Our review will not focus on the laboratory experiments and failures, not because they are assumed to be insignificant, but due to the fact that the aftermath of these events does not have a catastrophic impact to the environment, society and economy compared to the industrial accidents analyzed in this review. However, these laboratory failures should teach us the lessons of preparedness and respect for nuclear energy in order to avoid or at least minimize the possibility of the occurrence of industrial disasters.

Before continuing further to the brief description of the most known events, we believe that is relevant to describe the International Nuclear and Radiological Event (INES) scale established in 1990 by the International Atomic Energy Agency (IAEA). As described on the IAEA official website, all members of IAEA make use of the 1-to-7 scale when a nuclear event occurs in order to describe its severity, with 1 being the lowest value and referring to a simple anomaly, and 7 being the worst instance of nuclear disaster and officially referred to as a "major accident".

As seen in Figure 1, values 1 to 3 indicate incidents with not so severe impacts on the environment and society in total, while values 4 to 7 indicate nuclear accidents that are catastrophic in most case outcomes. Although the scale was created in 1990, after the occurrence of some of the greatest nuclear accidents, scientists estimated the given INES Scale score for those events as well.

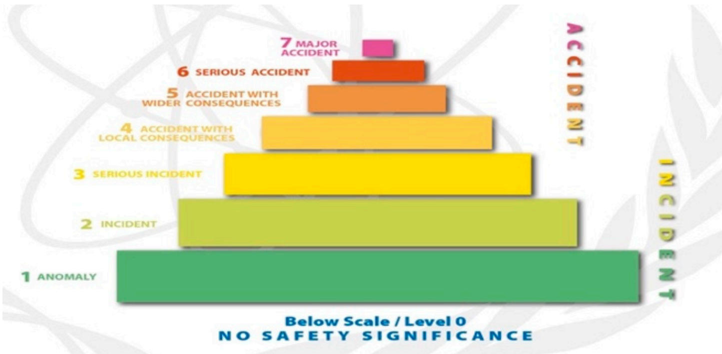

Figure 1. International Nuclear and Radiological Event (INES) Scale. Source: International Atomic Energy Agency official website—https://www-news.iaea.org/InesScale.aspx (accessed on 5 May 2022).

2.6.1. Three Mile Island (1979)

Perrow (1981), just two years after the Three Mile Island event, mentioned that accidents are likely to happen; however, factors that can eliminate their occurrence or impact do exist. The partial meltdown of the Three Mile Island Unit 2 reactor (TMI 2) occurred on 28 March 1979, in Pennsylvania, USA, causing a nuclear accident with high levels of radiation diffusion that experts categorized as a level-5 nuclear accident on the INES scale. As Perrow (1981) mentions, although some industrial accidents can be predicted and their occurrence can be prevented, Three Mile Island was not one of them. The literature tended to describe this event as a "normal accident"; however, Hopkins (2001) criticizes Perrow's "normal accident theory" by explaining that major accidents tend to occur due to management failures, and more specifically due to the lack of the communication of information. More specifically, Hopkins (2001) emphasizes the fact that Perrow's theory was endeavoring to shift the blame away from front line operators.

2.6.2. Chernobyl (1986)

The worst disaster in nuclear history occurred on 26 of April 1986. As Jaworowski (2010) states, the Chernobyl disaster is believed to be the worst possible catastrophe since the advent of nuclear energy. As the records mention, it was the early hours of 26 April when Chernobyl personnel ran a safety test on a flawed reactor design. The fact that this specific test was held during the night shift with insufficiently trained personnel, together with human errors and inaccurate decisions, led to the misuse of the No. 4 reactor, whose power dropped unexpectedly, causing consecutive failures and finally the reactor's shutdown. This moment was the beginning of the deadliest and most catastrophic nuclear disaster in history so far. The explosion following this event destroyed a huge part of the nuclear power plant, and radiation was diffused uncontrollably. The International Atomic Energy Agency (IAEA) categorized this catastrophe as a level-7 major accident on the INES scale.

The Vladimir Lenin Nuclear Power Plant, or Chernobyl Nuclear Power Plant as it is commonly known, is located close to the city of Pripyat, Ukraine, close to the Belarus-Ukraine border (16 km), and 100 Km north of Kyiv, the capital city of Ukraine. After this devastating accident, Pripyat turned into an abandoned city due to high levels of radiation and contamination. It is firmly believed that neighbor cities and countries have faced the negative impact of this disaster mainly due to transboundary pollution. Jaworowski (2010), illustrates that in the days following the accident, the recorded concentration of radiocesium over Poland was 2% to 6% of the maximum level of at the ground level, where the maximum equals 36.1 mBq/m^3. The outcomes of the Chernobyl disaster are uncountable. Not only was it enormous economic disaster due to the collapse of a great part of the reactor, but the whole NPP was abandoned and therefore out of order, which led to a reduction in electricity production. The government had to face the evacuation and relocation of the population from the hazardous areas. Both the health and environmental impacts were tremendous. Jaworowski (2010) examined the cancer risk factor of the nuclear workers, not only in Chernobyl but also in other countries such as Canada, the USA and the United Kingdom. However, it is crucial to mention that the level of cancer in the general population increased in the neighbor areas of the accident due to the uncontrollable diffusion. The most commonly observed cancer in those areas, as an aftermath of the accident, was thyroid cancer and leukemia, and was mainly diagnosed in children (Moysich et al. 2002).

2.6.3. Fukushima (2011)

In contrast to other nuclear disasters, the Fukushima Daiichi Nuclear Power Plant disaster was not an accident caused due to human errors or misconceptions. More specifically, on 11 March 2011, a 9 MW earthquake close to the north-eastern coast of Honshu (Japan) triggered a series of large tsunami waves which devastated all regional coastal areas (Kenta and Managi 2016; Managi and Guan 2017; Behling et al. 2019). As Halkos and Zisiadou (2020b) state, this series of events led to a shutdown of 11 nuclear power plants. Regarding the Fukushima Power Plant, a shutdown of its cooling system due to the flood of the tsunami waves caused the most catastrophic nuclear accident since Chernobyl. The International Atomic Energy Agency (IAEA) initially categorized this catastrophe as a level-5 accident on the INES scale. However, after reassessment, the score was upgraded to level-7 (Halkos and Zisiadou 2020b), a score that to that point had only been given to the Chernobyl disaster (Norio et al. 2011).

2.7. Nuclear Weapons

Nuclear energy can be a blessing or a curse, depending on the way someone uses it. As we have already mentioned, science and scientific achievements are not dangerous for humanity. What makes them dangerous and sometimes catastrophic, however, is the way humans handle them. In other words, the misuse, the overuse or the inappropriate way of adopting and using scientific achievements is what may cause fatalistic consequences. An example of such a case is the use of atomic bombs, also known as nuclear weapons. Einstein's famous equation regarding energy ($E = mc^2$) can turn into the deadliest weapon in the wrong hands.

2.7.1. Nuclear Weapons Used in Military Attacks

Following the latest news regarding the Russo-Ukrainian war, we would like to present the first and only two uses of nuclear weapons as a reminder of. Although nuclear energy has been described above as a source of electricity production, with its benefits and drawbacks, the real case was not always like that. More specifically, during World War II, the world witnessed the first and last time that military authorities decided to use the power of nuclear science as a form of attack. These two attacks became the sharpest memory of World War II, and passed from generation to generation as the most catastrophic military missions. The cities of Hiroshima and Nagasaki became globally famous overnight as the victims of these American attacks.

Hiroshima (1945)

Hiroshima was the first target city of the atomic bombing. As Zolberg (1998) mentions, on 6 August 1945, the American Boeing B-29 Superfortress, also known as the Enola Gay, flown by Paul Tibetts, dropped the first nuclear weapon above Hiroshima. The atomic bomb was called "Little Boy", with a blast yield equal to 15 Kilotons (Kt), and caused more than 90,000 fatalities.

Nagasaki (1945)

Similar to the Hiroshima case, another Japanese city had to face a nuclear attack three days after the initial mission. Specifically, another American Boeing B-29 Superfortress, known as Bockscar, flown by Charles Sweeney, attacked Nagasaki on 9 August 1945. The atomic bomb was called "Fat Man", with a blast yield equal to 21 Kilotons (Kt), and caused more than 39,000 fatalities.

2.7.2. Nuclear Weapons under Testing

As can be seen in Figure 2, "Little Boy" and "Fat Man" were not the only two nuclear weapons created in history. However, the rest of the weapons were not used during warfare but were only tested from laboratories. The representation in Figure 2 was created by Los Alamos National Laboratory, which is the laboratory that designed "Little Boy" and "Fat Man". Since the last atomic bombing, three more confirmed tests were run globally, the "Castle Bravo" in 1951, the "Tsar Bomba" in 1961 and the Licorne in 1970.

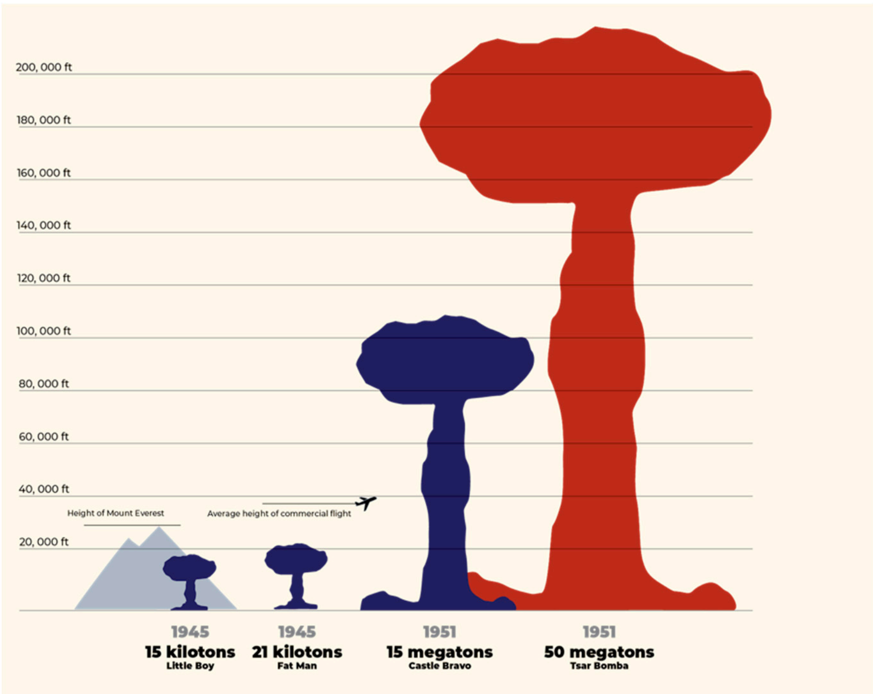

Figure 2. Nuclear Weapons Comparison. Source: Los Alamos National Laboratory (LANL) https://www.lanl.gov/discover/publications/national-security-science/2020-summer/vela-feature.shtml (accessed on 5 May 2022).

In 1951, just 6 years after the atomic bombing during World War II, the US Government decided to create and test another nuclear weapon under the name of "Castle Bravo", which was several times more powerful than "Little Boy" and "Fat Man". As reported, the "Castle

Bravo" blast yield equalled 15 Megatons (Mt). Following the American testing, Russia, then the Soviet Union, launched and tested its own nuclear weapon in 1961, under the name "Tsar Bomba", meaning the King of Bombs, with a blast yield equal to 50 Megatons (Mt), which was the greatest nuclear weapon created to date. Another test that has been ran and not represented in Figure 2 was the French nuclear weapon tested in 1970, under the name of "Licorne", with a blast yield equal to 1 Megaton (Mt), significantly smaller compared to previous tests.

Brook et al. (2014) in their paper make a reference to nuclear weapons. More specifically, they explain that in order for a country or industry to produce nuclear weapons, they should ensure access to the main weapons-grade materials of high purity such as the isotope Pu-239 or the isotope U-235. Regarding the isotope Pu-239, this element is obtained by the irradiation of U-238, while the isotope U-235 is produced by enrichment from the mined natural uranium. Knowing that the availability of those chemical elements is unlimited in nature, we can assume that the production of those weapons is a simple task for countries that already have the know-how, the facilities and the technology required. In other words, countries that have nuclear power plants can easily produce nuclear weapons. The danger that is hidden behind such actions and the increased fear and uncertainty regarding nuclear weapons after the Hiroshima and Nagasaki cases triggered powerful countries to establish an anti-nuclear weapon treaty.

2.7.3. Non-Proliferation Treaty

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) was initially proposed and signed in 1968, having as its main goal the prevention of nuclear weapons proliferation around the world. Currently, most countries have signed the Non-Proliferation Treaty, which for them is a commitment to reducing the production, spread and use of nuclear weapons (Brook et al. 2014). The responsibility of ensuring that the Treaty will be respected and followed by all members was assigned to the United Nations. More specifically, the International Atomic Energy Agency (IAEA) is responsible for the verification of adherence by all member states to the Non-Proliferation Treaty. As Brook et al. (2014) mention, no production of weapons-grade materials is observed globally, with the only exception being the dual-purpose RBMK-type reactors that have been constructed in the Soviet Union. The Non-Proliferation Treaty consists of 11 Articles (Article I–Article XI) which promote global safety regarding the nuclear weapons. As the Treaty mentiones in Article X, paragraph 2, with the completion of the first 25 years of its effectiveness, a conference should be held in order to evaluate the progress of the Treaty and decide on its continuation, a conference that the United Nations held and where the continuation of the Treaty was agreed upon by the parties involved.

3. The Energy Scheme of the New Millennium

The global community is watching the warfare in Europe between Russian Federation and Ukraine with intense concern since, in addition to the stakes of democracy, it has affected the global economy and the production and supply of energy. Russia is one of the main energy suppliers in terms of natural gas, a source that is used in electricity production as well as a heating fuel in many countries across the world. Moreover, the production line relies on electricity, which nowadays became a mercurial component due to the occurring limitations.

Over the last years, countries across the world, taking into consideration climate change as well as the reduction of the inventory of fossil fuels, have attempted to adopt alternative and specifically renewable forms of energy production. The most common sources of energy have already been mentioned in previous sections. Based on available data, we are aiming to illustrate the current situation since the beginning of the new millennium by using the reported values by BP's *Statistical Review of World Energy* (BP 2022).

Methodology

Before we analyze the results presented in Tables A1 and A2, we need to clarify the methodology used in order to create the tables presented below. Tables present the total values of energy and electricity production globally per year. We calculated the share of production of each type of energy and electricity source by dividing the total value (last column of each table) by the value of each type of energy and electricity source. The summations per year and the percentages based on the total energy mix were calculated by the authors. The number of countries using each specific form of energy source were calculated by the authors simply by subtracting the zero filled countries of the total 79 countries of the sample regarding the energy mix and the 207–209 countries regarding the electricity production.

Initially, we observed the energy mix used since 2000 on an annual basis for the reported countries. Table A1 (Appendix A) presents the summations per energy source per year over the last 22 years (2000–2021). As we can observe, nine different possible energy sources are reported, including biofuels, solar, wind and hydroelectric power, nuclear energy, gas, coal, oil, and finally geothermal, biomass, and other energy sources. As is mentioned in the BP database (2022), the values reported refer to TWh. Following the note of Table A1 (Appendix A), we will initially discuss the results of the total energy mix per year due to the fact that the records in brackets are based on these values. First and foremost, the total energy mix per year is the summation of all forms of energy sources of all 79 included countries. What is illustrated is the fact that, since the beginning of the new millennium and over time, the total amount of energy needed, produced and consumed by the nations globally is steadily increasing. More specifically, there has been a 48.61% increase in the total energy mix over the last 22 years, reaching 158,160.8 TWh of energy in Total. This significant increase indicates the excessive need of energy by society, which can lead us to worst case scenarios regarding the latest energy crisis observed due to the aforementioned warfare. The world demands greater amounts of TWh year by year, amounts that may not be able to be produced due to the lack of natural resources such as gas or fossil fuels.

Another aspect that is crucial to take into consideration is the sources from which all this energy amount is produced. In 2000, the three main sources of energy mix were gas, coal and oil, which covered the 22.131%, 25.364% and 38.529% of total energy mix, respectively. More specifically, in total, 91,551.77 TWh were produced based on these three energy sources, when the total amount of energy produced globally was reaching the 106,425.3 TWh. The majority of the countries examinedwere basing their energy on those sources, whereby 76 countries were using gas, 71 were using coal, and all 79 were using oil. Regarding the share of energy coming from the renewable energy forms including solar, wind and hydroelectric power in 2000, the values reported were significantly low. Only 6.825% of the total energy produced came from solar (0.003%), wind (0.087%) and hydroelectric (6.735%) power. Although 70 countries have already adopted the hydroelectric power as an alternative source of energy, only 7167.738 TWh were produced globally, while solar and wind power were used only by 28 and 39 countries, respectively, with their share of the total energy mix being dramatically low.

As the task here is to review the case of nuclear energy, in 2000, nuclear energy was adopted by 30 countries, providing 7317.65 TWh in total, reaching the share of 6.876% of the total energy mix. The number of countries trusting nuclear energy is low compared to other sources, which have been proven to be pollutants such as coal. A possible reason for the non-use of nuclear energy may be assumed to be the negative theory regarding the nuclear accidents. Indeed, history has shown us that nuclear accidents can be deadly and disastrous for the economy, the society and the environment. However, it is important to weigh the drawbacks of other sources of the energy mix. Oil spills cause great environmental disasters as well; however all 79 countries included in BP's review use oil as one of the main sources of energy. The production of energy using coal has been proven to be harmful both for the environment and human life, and today the world still depends on coal for a significant part of its energy production.

The Energy Mix scheme has drastically changed in 2021. The three main sources of energy mix were gas, coal and oil, which accounted for 24.834%, 27.743% and 30.648% of the total energy mix, respectively. More specifically, in total, 131,629.22 TWh were produced based on these three energy sources, when the total amount of energy produced globally was reaching 158,160.8 TWh. The majority of the countries examined were basing their energy on those sources, and 76 countries were using gas, 75 were using coal, and all 79 were using oil. Regarding the share of energy coming from the renewable energy forms including solar, wind and hydroelectric power in 2021, the values reported are still significantly low, however, there has been a noticeable increase. Only 11.192% of the total energy produced came from solar (1.685%), wind (3.049%) and hydroelectric (6.458%) power. What is really important to mention, however, is the number of countries adopting renewable sources of energy. Compared to 2000, in 2021 the majority of countries have turned to more ecofriendly sources of energy. Currently, solar power is used in 78 out of 79 countries included in the research, indicating a sharp increase compared to the 28 countries in 2000. Similarly, wind power is used in 70 out of 79 countries, where in 2000 only 39 countries were using wind power as part of their energy mix.

The energy produced by the renewable forms has significantly increased. Solar power in 2000 was producing only 3.11549 TWh globally, while in 2021 the energy produced by solar power equals 2664.65 TWh, giving 854.28 times more energy production based on solar power. Similarly, wind power produced 51.35 times more energy in 2021, while hydroelectric power produced 0.42 times more energy. However, regarding the low percentage change of hydroelectric power, we need to take into consideration the fact that solar and wind power were established in many countries as new sources of energy, while hydroelectric power was already prevalent as a source of energy. These changes indicate that communities around the world have started changing, or at least enhancing the energy mix with ecofriendly options, taking into account the climate change phenomenon and its impacts to the environment.

Moving forward, as of 2021 nuclear energy has been adopted by 32 countries, providing 7026.322 TWh in total, reaching the share of 4.443% of the total energy mix. Although there was a slight increase in the number of countries using nuclear power, from 30 to 32 countries, what is observable is the fact that the TWh produced globally in 2021 were 291.33 TWh less than those produced in 2000. More specifically, the global production of nuclear energy in 2021 was 3.98% lower compared to the 2000 values. This decrease may indicate a possible hesitancy with regard to the use of nuclear energy.

Using the same Review by BP (2022) and the data published, it is feasible to display the existing condition regarding the electricity production specifically and not just with regard to the energy mix in general. The difference between those two terms is the fact that electricity constitutes one of the three components of energy, while transport and heating constitute the other two components.

When facing energy crises similar to the one that is currently occurring in the world, it is crucial to know the share of electricity, and not only energy, produced by each source. This knowledge will give us the needed information to create a plan regarding each country's autonomy.

Table A2 (Appendix A) presents the summations per electricity source per year over the last 21 years (2000–2020). As we can observe, eight different possible electricity sources are reported, including solar, wind and hydroelectric power, nuclear energy, gas, coal, oil, and finally renewables including bioenergy and other electricity sources. As is mentioned in the BP database (2022), the values reported refer to TWh. Following the note of Table A2 (Appendix A), we will initially discuss the results of the total electricity per year due to the fact that the records in brackets are based on these values. First and foremost, the total electricity per year is the summation of all forms of energy sources of all included countries. What is illustrated is the fact that, since the beginning of the new millennium and over time, the total amount of electricity needed, produced and consumed by nations globally is steadily increasing. More specifically, there has been a 74.30% increase in total electricity over the last 21 years, reaching 26,106.839 TWh of electricity in total. This significant increase indicates the excessive need for electricity by society, which can worry us once again about the worst case scenarios regarding the latest energy crisis observed due to the present warfare that is taking place.

Figure 3 shows a stacked bar graph which has been constructed in an attempt to visualize the evolution of the global energy mix per year since the beginning of the new millennium. It has been created using the share of energy coming from each specific source to the total energy produced annually.

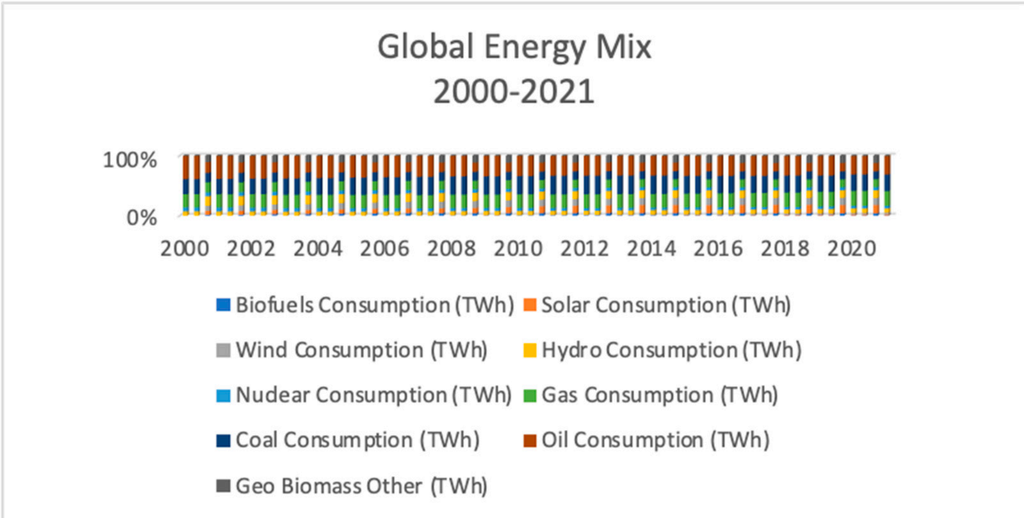

Figure 3. Global Energy Mix (2000–2021). Constructed by the authors.

Another aspect that is crucial to take into consideration is the source from which all of the total electricity amount is produced. In 2000, the main sources of electricity were coal and gas, and the three most common electricity sources were hydroelectric power and oil, which which accounted for 38.153%, 17.969% and 17.527% of total electricity, respectively. More specifically, in total, 11,031.31 TWh were produced based on these three electricity sources, when the total amount of electricity produced globally was reaching 12,978.305 TWh. The majority of the countries studied were basing their energy on those sources, whereas 91 countries were using gas, 70 were using coal, and 146 were using hydroelectric power. Regarding the share of energy coming from the renewable energy forms including solar and wind power in 2000, the values reported were significantly low. Only 0.215% of the total energy produced came from solar (0.007%) and wind (0.208%) power. Another source that has not been discussed yet regarding electricity production is oil.

In contrast to the energy mix analyzed above, oil as a form of electricity source is not a common component. More specifically, in 2000, 175 countries globally were using oil in the electricity production process; however, only 1191.85 TWh were being produced using this source, accounting for a share of 7.957% of total electricity. Moving forward, we once again are aiming to separately discuss the case of nuclear energy. In 2000, the electricity production of nuclear energy was adopted by 31 countries providing 2505.93 TWh in total, reaching the share of 16.730% of total electricity. Similar to the energy mix, the number of countries trusting nuclear energy is low compared to other sources that have been proven to be pollutants, such as coal.

Following the same path of the energy mix scheme, electricity production has drastically changed in 2020. The three main sources of electricity were coal, gas and hydroelectric power, which were covering 35.296%, 23.047% and 16.516% of total electricity, respectively. More specifically, in total, 19,543.22 TWh were produced based on these three electricity sources, while the total amount of electricity produced globally was reaching 26,106.839 TWh. With regard to the share of energy coming from the renewable energy forms including solar and wind power in 2020, the values reported are still significantly low; however, there has been a noticeable increase. Only 9.276% of the total energy produced came from solar (3.197%) and wind (6.079%) power. What is really important to mention, however, is the number of countries adopting renewable sources of energy. Compared to 2000, in 2020 the majority of countries have turned to more ecofriendly sources of energy. Currently, solar power is used in 151 out of 209 countries included in the research, indicating a sharp increase compared to the 15 out of 207 countries in 2000. Similarly, wind power is used in 105 out of 209 countries, where in 2000 only 36 out of 207 countries were using wind power as part of their electricity production.

The electricity produced by the renewable forms has significantly increased. Solar power in 2000 was producing only 1.08 TWh globally, while in 2020 the electricity produced by solar power equalled to 834.63 TWh, providing 771.81 times more electricity production based on solar power. Similarly, wind power produced 49.93 times more energy in 2020. Once again, these changes indicate that communities around the world have started changing, or at least enhancing the energy mix with ecofriendly options, taking into account the climate change phenomenon and its impacts to the environment.

Moving forward, in 2020 energy production resulting from nuclear energy was adopted by 33 countries, providing some 2635.81 TWh in total, accounting for 10.096% of total electricity. Although there was a slight increase in the number of countries using nuclear power, from 31 to 33 countries, what is observable is the fact that the share of electricity produced by nuclear energy globally in 2020 is lower compared to the share from 2000.

Figure 4 is a stacked bar graph which has been constructed in an attempt to visualize the evolution of global electricity per year since the beginning of the new millennium. As is obvious, it has been created using the share of energy coming from each specific source to the total energy produced annually.

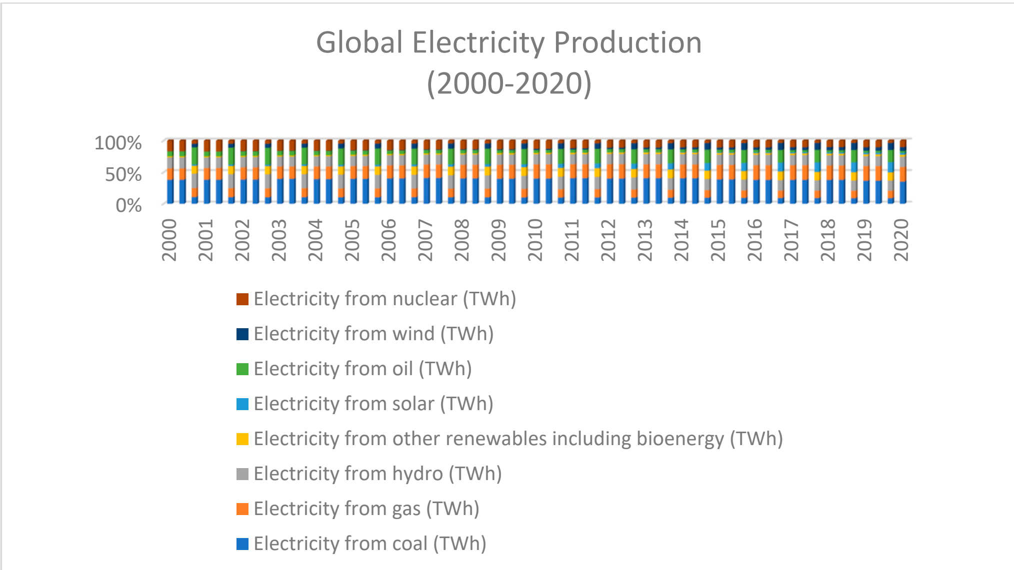

Figure 4. Global Electricity Production (2000–2020). Constructed by the authors.

4. Conclusions

The purpose of this paper was to review the case of nuclear energy and to discuss the issue of coping with energy crisis risks. More specifically, apart from presenting the basics of nuclear energy and nuclear reactors, we attempted to compare this source of electricity with other renewable energy forms such as solar power, wind power and hydroelectric power. It has been seen that, over the last years, there has been an increase in reactor construction globally. Having as an example the countries that gain the majority of their electricity from nuclear power plants, such as France, even more countries have decided to invest in this source of energy.

Supporters of nuclear energy believe that this source of power can be the best solution for sustainable energy production as well as climate change. The fact that during nuclear power production there are no emissions of greenhouse gases and carbon dioxide makes this source of energy a clean and eco-friendly option. The factor that supports its sustainability is uranium, the fuel used during production, which apart from being inexpensive is also unlimited in nature. Renewable energy forms (solar, wind and hydroelectric power) may be great options regarding eco-friendly energy production, but they unfortunately appear to be unsustainable due to their limited availability, making them likely unable to meet daily energy demands.

Nuclear energy, on the other hand, requires expensive investments in equipment and facilities, as well as expensive methods of waste management and disposal. The fact that the waste produced is radioactive and remains radioactive for hundreds of thousands of years, raising great concern about the negative impact that this may have to human beings and/or the environment with regard to potential cases of misuse. Another drawback of nuclear power plants is the fact that they are extremely vulnerable to natural environmental hazards such as earthquakes and tsunamis. The case of the Fukushima Daiichi Nuclear Power Plant Disaster of 2011 serves as a reminder of this.

Regarding the increase of income and the increase of environmental degradation up to a specific level of income and the decrease of environmental pollution afterwards, as proposed by the Environmental Kuznets Curve hypothesis, this has been proven to be accepted as the case in some countries (Halkos 1996, 2003, 2013). Moreover, some countries have proven that there is a causal relationship between economic growth and energy consumption. However, this has not been proven in all cases.

As is presented in the paper, since the beginning of the new millennium the scheme of energy production and electricity production appears to have changed drastically. By using the available data reported by BR, we illustrated that the production of energy and electricity has increased over the last 22 years (2000–2021) due to the excessive demand; however, what is more important to mention is the share of both electricity and energy derived from renewable forms such as solar, wind and hydroelectric power. It has been shown that more and more countries have adopted those sources of energy compared to previous decades.

What is important to examine, however, is whether nuclear energy appears to be trustable as a source of energy production by the nations of the world. As we have seen above, over the last 22 years there has been a slight increase in the number of nations trusting nuclear sources of energy both in terms of energy production and electricity production. Nuclear energy has been adopted by more countries over the last two decades, yet regarding the electricity production only 33 out of the 209 countries included in BP's sample use nuclear energy in order to produce electricity. These values indicate that it is probable that most countries either do not trust this source of energy or there may be an economic reason behind this situation. Knowing that nuclear power plants are an expensive investment, countries may avoid the investment in these facilities. Another possible scenario may be the combination of those two cases, as both the expense of investment and the risk of nuclear power plants may have led to a slight increase of nuclear energy adoption globally. Regarding renewable forms of energy, it has been proven that more and more nations around the world trust and adopt these sources in order to cover a part of their needed energy and electricity production. There has been a sharp increase in the countries creating power plants for renewable sources of energy such as hydroelectric power, solar and wind power. There has been a reported increase in their share of global production. To the best of our knowledge, there is no evidence as to whether there is a better source of energy when comparing the reported forms.

Lastly, when discussing the case of nuclear energy, we should of course mention all the aspects connected to the subject, but we have to always remember the nuclear accidents, which, although they may not happen frequently, the results are disastrous for the economy, the environment and human health. They can either be caused by human error or by acts of nature, but the aftermath is always the same, leaving devastated and abandoned regions with people suffering from chronic illnesses and probable increases in cancer rates, if not immediate death.

Regarding further research, we would like to mention that it is crucial to examine which alternative sources have proven to provide sufficient energy for peak demands and what their impact to the environment is based on their production process. Moreover, it is important to investigate and analyze the taxonomy regulations established by countries and organizations and provide evidence whether nuclear energy and renewable energy sources can be a possible solution to the European or global energy crisis, as well as to use those forms as an instrument to enhance climate protection and provide greener alternatives for a more prosperous future.

Funding: The research received no external funding.

Data Availability Statement: Data available on https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Energy Mix by source (all in TWh).

World	Biofuels	Solar	Wind	Hydro	Nuclear	Gas	Coal	Oil	Geo Biomass Other	Total Energy Mix
2000	114.3912 [0.107%] 8	3.115499 [0.003%] 28	92.11011 [0.087%] 39	7167.738 [6.735%] 70	7317.65 [6.876%] 30	23,552.75 [22.131%] 76	26,994.11 [25.364%] 71	41,004.91 [38.529%] 79	178.5533 [0.168%] 48	106,425.3
2001	110.8154 [0.103%] 8	4.155243 [0.004%] 29	111.9642 [0.104%] 43	6932.966 [6.456%] 70	7475.607 [6.961%] 30	23,839.47 [22.198%] 76	27,420.84 [25.533%] 74	41,312.93 [38.469%] 79	185.3455 [0.173%] 51	107,394.1
2002	140.2483 [0.128%] 13	5.221885 [0.005%] 31	151.7197 [0.138%] 44	6999.372 [6.381%] 70	7545.317 [6.878%] 30	24,529.58 [22.361%] 76	28,508.64 [25.988%] 75	41,617.19 [37.938%] 79	199.8919 [0.182%] 52	109,697.2
2003	159.5752 [0.140%] 14	6.500787 [0.006%] 31	182.5275 [0.161%] 46	6923.877 [6.095%] 70	7345.786 [6.467%] 30	25,198.69 [22.183%] 76	31,040.4 [27.326%] 74	42,525.45 [37.436%] 79	211.0865 [0.186%] 52	113,593.9
2004	191.2764 [0.160%] 17	8.510881 [0.007%] 35	245.5105 [0.206%] 52	7409.625 [6.216%] 70	7630.364 [6.401%] 30	26,148.16 [21.935%] 76	33,196.87 [27.848%] 74	44,149.89 [37.036%] 79	227.9709 [0.191%] 55	119,208.2
2005	230.3407 [0.187%] 19	11.90605 [0.010%] 37	298.5086 [0.243%] 53	7617.337 [6.192%] 70	7600.611 [6.179%] 30	26,850.21 [21.828%] 76	35,695.61 [29.018%] 74	44,458.48 [36.142%] 79	247.37 [0.201%] 55	123,010.4
2006	288.3931 [0.228%] 22	16.28421 [0.013%] 38	378.4353 [0.299%] 57	7878.779 [6.227%] 70	7647.21 [6.044%] 30	27,560.27 [21.782%] 76	37,584.38 [29.704%] 75	44,911.86 [35.495%] 79	262.9176 [0.208%] 57	126,528.5
2007	379.0338 [0.291%] 22	21.95076 [0.017%] 40	483.5379 [0.371%] 59	7958.067 [6.099%] 70	7444.62 [5.706%] 30	28,659.4 [21.966%] 76	39,783.74 [30.492%] 75	45,456.76 [34.840%] 79	286.0014 [0.219%] 58	130,473.1
2008	510.4845 [0.387%] 22	35.42512 [0.027%] 45	620.8337 [0.471%] 60	8406.951 [6.375%] 70	7375.647 [5.593%] 30	29,357.17 [22.261%] 76	40,301.37 [30.560%] 75	44,961.1 [34.094%] 79	305.3945 [0.232%] 60	131,874.4

Table A1. *Cont.*

World	Biofuels	Solar	Wind	Hydro	Nuclear	Gas	Coal	Oil	Geo Biomass Other	Total Energy Mix
2009	579.0933 [0.446%] 23	58.49998 [0.045%] 52	770.5533 [0.594%] 61	8330.405 [6.419%] 70	7226.256 [5.568%] 30	28,762.58 [22.163%] 76	39,744.99 [30.626%] 74	43,977 [33.886%] 79	327.9855 [0.253%] 62	129,777.4
2010	664.4033 [0.488%] 24	93.42596 [0.069%] 59	958.3268 [0.704%] 61	8698.284 [6.393%] 70	7367.101 [5.414%] 29	30,885.52 [22.699%] 76	41,565.2 [30.548%] 75	45,463.5 [33.413%] 79	369.0992 [0.271%] 62	136,064.9
2011	696.9326 [0.500%] 24	179.6672 [0.129%] 66	1210.853 [0.868%] 62	8821.638 [6.327%] 70	7015.404 [5.031%] 30	31,631.98 [22.685%] 76	43,581.74 [31.255%] 75	45,909.24 [32.925%] 79	390.4146 [0.280%] 63	139,437.9
2012	717.1511 [0.508%] 24	276.3121 [0.196%] 71	1448.305 [1.025%] 62	9155.181 [6.480%] 70	6494.912 [4.597%] 30	32,457.17 [22.972%] 76	43,761.25 [30.972%] 76	46,558.83 [32.952%] 79	422.5592 [0.299%] 63	141,291.7
2013	775.1474 [0.539%] 24	375.1109 [0.261%] 76	1722.897 [1.199%] 67	9435.65 [6.565%] 70	6507.32 [4.527%] 30	32,974.96 [22.942%] 76	44,430.93 [30.913%] 76	47,050.79 [32.736%] 79	456.5064 [0.318%] 65	143,729.3
2014	823.7569 [0.567%] 24	528.3576 [0.364%] 76	1898.331 [1.307%] 68	9668.559 [6.657%] 70	6600.271 [4.545%] 29	33,146.83 [22.823%] 76	44,727.26 [30.797%] 76	47,346.81 [32.600%] 79	493.7744 [0.340%] 65	145,233.9
2015	856.9625 [0.586%] 24	679.3229 [0.464%] 76	2216.853 [1.515%] 69	9608.963 [6.569%] 70	6648.553 [4.545%] 30	33,834.85 [23.130%] 76	43,615.22 [29.815%] 76	48,291.22 [33.012%] 79	532.091 [0.364%] 68	146,284
2016	893.1888 [0.602%] 24	865.4356 [0.584%] 77	2549.634 [1.720%] 67	9859.68 [6.650%] 69	6708.681 [4.525%] 30	34,611.59 [23.344%] 76	43,027.98 [29.021%] 76	49,210.73 [33.191%] 79	540.1048 [0.364%] 68	148,267
2017	912.9255 [0.605%] 24	1171.459 [0.776%] 78	3006.434 [1.991%] 67	9928.638 [6.577%] 69	6728.184 [4.457%] 30	35,571.81 [23.562%] 76	43,175.31 [28.599%] 76	49,898.69 [33.052%] 79	576.2781 [0.382%] 69	150,969.7
2018	983.5064 [0.634%] 24	1505.385 [0.971%] 78	3323.316 [2.144%] 68	10,106.86 [6.519%] 69	6850.746 [4.419%] 30	37,376.67 [24.110%] 76	43,720.89 [28.202%] 76	50,538.79 [32.600%] 79	621.7367 [0.401%] 69	155,027.9
2019	1049.003 [0.671%] 24	1829.434 [1.171%] 78	3699.318 [2.367%] 70	10,250.11 [6.558%] 69	7067.73 [4.522%] 30	38,058.26 [24.351%] 76	43,071.78 [27.559%] 76	50,613.4 [32.384%] 79	651.8196 [0.417%] 69	156,290.9
2020	996.0236 [0.664%] 24	2191.175 [1.461%] 78	4145.35 [2.765%] 69	10,492.24 [6.998%] 69	6782.355 [4.524%] 32	37,444.33 [24.975%] 76	41,311.4 [27.554%] 75	45,884.39 [30.604%] 79	681.3334 [0.454%] 69	149,928.6
2021	1065.024 [0.673%] 24	2664.65 [1.685%] 78	4821.799 [3.049%] 70	10,214.18 [6.458%] 69	7026.322 [4.443%] 32	39,277.3 [24.834%] 76	43,878.03 [27.743%] 75	48,473.89 [30.648%] 79	739.5754 [0.468%] 69	158,160.8

Note: The table illustrates the TWh produced by each specific form of energy source, the values in the brackets report the percentage of total energy produced by each specific form of energy source, while the values in the parentheses represent the number of countries each form of energy source by year. Regarding the sample, 79 countries were included in the sample by BP during the time span 2000–2021. The summations per year and the percentages based on the total energy mix were calculated by the authors. The number of countries using each specific form of energy source were calculated by the authors simply by subtracting the zero filled countries of the 79 countries of the sample.

Table A2. Sources of Produced Electricity (all in TWh).

World	Electricity from Coal	Electricity from Gas	Electricity from Hydro	Electricity from Other Renewables Including Bioenergy	Electricity from Solar	Electricity from Oil	Electricity from Wind	Electricityfrom Nuclear (TWh)	Total Electricity
2000	5714.63 38.153% 70	2691.5 17.969% 91	2625.18 17.527% 146	216.975 1.449% 79	1.08 0.007% 15	1191.85 7.957% 175	31.16 0.208% 36	2505.93 16.730% 31	14,978.305
2001	5800.45 38.168% 69	2830.28 18.624% 92	2564.48 16.875% 147	210.898 1.388% 82	1.35 0.009% 17	1179.25 7.760% 174	38.17 0.251% 41	2572.31 16.926% 31	15,197.188
2002	6055.75 38.494% 69	3034.61 19.290% 93	2603.17 16.547% 149	225.229 1.432% 83	1.69 0.011% 18	1158.97 7.367% 177	52.06 0.331% 43	2600.35 16.529% 31	15,731.829
2003	6461.59 39.660% 70	3163.44 19.417% 95	2606.15 15.996% 151	238.931 1.467% 85	2.07 0.013% 18	1180.67 7.247% 177	63.44 0.389% 43	2576.19 15.812% 31	16,292.481
2004	6686.57 39.150% 70	3400.97 19.913% 95	2798.14 16.383% 150	256.838 1.504% 86	2.71 0.016% 19	1167.61 6.836% 176	85.27 0.499% 52	2681.18 15.698% 31	17,079.288
2005	7030.91 39.621% 72	3573.12 20.135% 97	2902.91 16.359% 150	280.742 1.582% 91	3.78 0.021% 20	1164.64 6.563% 177	103.9 0.586% 55	2685.38 15.133% 31	17,745.382
2006	7427.3 40.244% 73	3791.98 20.546% 97	3005.2 16.283% 150	297.064 1.610% 92	5.11 0.028% 22	1076.33 5.832% 176	132.8 0.720% 56	2719.87 14.737% 31	18,455.654
2007	7919.28 40.943% 73	4114.69 21.273% 98	3049.54 15.766% 151	321.125 1.660% 95	6.94 0.036% 27	1094.31 5.658% 178	170.93 0.884% 58	2665.34 13.780% 31	19,342.155
2008	7915.68 40.311% 73	4217.95 21.480% 98	3230.7 16.453% 151	336.825 1.715% 97	11.38 0.058% 30	1049.16 5.343% 176	220.09 1.121% 58	2654.51 13.518% 31	19,636.295
2009	7807.02 39.942% 73	4255.26 21.771% 99	3232.81 16.540% 152	364.058 1.863% 99	19.21 0.098% 36	974.4 4.985% 177	275.9 1.412% 64	2617.32 13.391% 31	19,545.978
2010	8346.96 39.961% 74	4687.57 22.442% 99	3409.23 16.322% 151	408.989 1.958% 103	31.08 0.149% 51	970.96 4.648% 177	346.22 1.658% 68	2686.63 12.862% 30	20,887.639

Table A2. *Cont.*

World	Electricity from Coal	Electricity from Gas	Electricity from Hydro	Electricity from Other Renewables Including Bioenergy	Electricity from Solar	Electricity from Oil	Electricity from Wind	Electricityfrom Nuclear (TWh)	Total Electricity
2011	8807.69 40.702% 78	4773.18 22.058% 102	3476.16 16.064% 152	430.049 1.987% 105	61.93 0.286% 59	1074.46 4.965% 181	439.9 2.033% 69	2576.2 11.905% 31	21,639.569
2012	8827.26 39.961% 78	5011.8 22.688% 102	3641.36 16.484% 152	459.53 2.080% 105	95.43 0.432% 69	1122.18 5.080% 182	528.9 2.394% 75	2403.18 10.879% 31	22,089.64
2013	9284.01 40.838% 79	4912.86 21.611% 102	3768.39 16.576% 152	496.037 2.182% 110	131.45 0.578% 81	1081.27 4.756% 182	640.06 2.815% 81	2419.42 10.643% 31	22,733.497
2014	9453.32 40.576% 81	5047.91 21.667% 102	3860.08 16.568% 152	535.863 2.300% 112	195.9 0.841% 103	1019.78 4.377% 180	716.8 3.077% 91	2468.28 10.594% 30	23,297.933
2015	9134.76 38.765% 83	5379.57 22.829% 102	3869.91 16.423% 152	568.046 2.411% 117	254.23 1.079% 114	1027.27 4.359% 181	829.08 3.518% 96	2501.5 10.616% 31	23,564.366
2016	9186.42 37.965% 83	5625.7 23.250% 103	3999.9 16.531% 151	581.325 2.402% 119	328.48 1.358% 127	982.41 4.060% 181	959.41 3.965% 100	2533.12 10.469% 31	24,196.765
2017	9476.27 38.093% 84	5729.38 23.031% 105	4049.15 16.277% 151	608.876 2.448% 119	443.29 1.782% 140	884.9 3.557% 181	1136.94 4.570% 100	2548.19 10.243% 31	24,876.996
2018	9837.67 38.051% 83	5859.29 22.663% 108	4170.02 16.129% 150	654.59 2.532% 120	567.8 2.196% 145	876.2 3.389% 182	1268.43 4.906% 104	2620.13 10.134% 31	25,854.13
2019	9617.54 36.581% 84	6083.4 23.139% 108	4219.16 16.048% 151	688.912 2.620% 119	694.5 2.642% 151	843.58 3.209% 181	1420.08 5.401% 106	2723.79 10.360% 31	26,290.962
2020	9214.62 35.296% 83	6016.79 23.047% 108	4311.81 16.516% 154	712.899 2.731% 119	834.63 3.197% 151	793.34 3.039% 181	1586.94 6.079% 105	2635.81 10.096% 33	26,106.839

Note: The table illustrates the TWh produced by each specific form of electricity source, the values in the brackets report the percentage of total electricity produced by each specific form of electricity source, while the values in the parentheses represent the number of countries each form of electricity source by year. Regarding the sample, the provided dataset includes 207 countries for the period 2000–2004, 208 countries for the period 2005–2011, and 209 for the period 2012–2020 in the sample by BP during the time span 2000–2020. The summations per year and the percentages based on the total electricity were calculated by the authors. The number of countries using each specific form of energy source were calculated by the authors simply by subtracting the zero filled countries of the total countries of the sample per year.

References

Adamantiades, Achilles, and Ioannis Kessides. 2009. Nuclear power for sustainable development: Current status and future prospects. *Energy Policy* 37: 5149–66. [CrossRef]

Akcay, Behiye. 2009. The case of nuclear energy in Turkey: From Chernobyl to Akkuyu nuclear power plant. *Energy Sources Part B* 4: 347–55. [CrossRef]

Akyuz, Emrah. 2015. Turkey's Nuclear Energy Policy and the Terrorist Threat. *The Journal of Academic Social Science Studies* 40: 523–36.

Akyuz, Emrah. 2017. Advantages and disadvantages of nuclear energy in Turkey: Public perception. *Eurasian Journal of Environmental Research* 1: 1–11.

Alam, Md Kausar, Mosab I. Tabash, Syed Mabruk Billah, Sanjeev Kumar, and Suhaib Anagreh. 2022. The Impacts of the Russia–Ukraine Invasion on Global Markets and Commodities: A Dynamic Connectedness among G7 and BRIC Markets. *Journal of Risk and Financial Management* 15: 352. [CrossRef]

Alkhalidi, Ammar, Tuqa Alrousan, Manal Ishbeytah, Mohammad Ali Abdelkareem, and Olabi Abdul Ghani. 2022. Recommendations for energy storage compartment used in renewable energy project. *International Journal of Thermofluids* 15: 100182. [CrossRef]

Al-Mulali, Usama, Ilhan Ozturk, and Hooi Hooi Lean. 2015. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. *Natural Hazards* 79: 621–44. [CrossRef]

Al-Mulali, Usama, Sakiru Adebola Solarin, and Ozturk Ilhan. 2016. Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: An autoregressive distributed lag (ARDL) approach. *Natural Hazards* 80: 1729–47. [CrossRef]

Aneke, Mathew, and Meihong Wang. 2016. Energy storage technologies and real life applications—A state of the art review. *Applied Energy* 179: 350–77. [CrossRef]

Apergis, Nicholas, and James Earl Payne. 2010. A panel study of nuclear energy consumption and economic growth. *Energy Economics* 32: 545–49. [CrossRef]

Aras, Erol. 2013. The necessity of nuclear energy in Turkey: A comparison with hydropower energy. *Energy Sources, Part B: Economics, Planning, and Policy* 8: 107–14. [CrossRef]

Bagher, Amina M., Mazian Abdul Vahid, and Mohsen Mirhabibi. 2014. Geothermal energy. *Journal of Engineering and Technology Research* 6: 146–50.

Barros, Carlos Pestana, and Shunsuke Managi. 2016. French nuclear electricity plants: Productivity and air pollution. *Energy Sources, Part B: Economics, Planning, and Policy* 11: 718–24. [CrossRef]

Barthelmie, Rebecca J., and Sara C. Pryor. 2021. Climate change mitigation potential of wind energy. *Climate* 9: 136.

Basit, Muhammad Abdul, Saad Dilshad, Rabiah Badar, and Syed Muhammad Sami ur Rehman. 2020. Limitations, challenges, and solution approaches in grid-connected renewable energy systems. *International Journal of Energy Research* 44: 4132–62. [CrossRef]

Behling, Noriko, Mark C. Williams, Thomas. G. Behling, and Shunsuke Managi. 2019. Aftermath of Fukushima: Avoiding another major nuclear disaster. *Energy Policy* 126: 411–20. [CrossRef]

BP. 2022. Statistical Review of World Energy. Available online: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html (accessed on 13 July 2022).

Bridgwater, Tony. 2006. Biomass for energy. *Journal of the Science of Food and Agriculture* 86: 1755–68. [CrossRef]

Brook, Barry W., Agustin Alonso, Daniel A. Meneley, Josef Misak, Tom Blees, and Jan B. van Erp. 2014. Why nuclear energy is sustainable and has to be part of the energy mix. *Sustainable Materials and Technologies* 1: 8–16. [CrossRef]

Cohen, Bernard L. 1983. *Before It Is Too Late*. New York: Springer Publishing.

Cooper, Mark. 2014. Small modular reactors and the future of nuclear power in the United States. *Energy Research & Social Science* 3: 161–77.

Corkhill, Claire, and Neil Hyatt. 2018. *Nuclear Waste Management*. Bristol: IOP Publishing, p. 1.

Coskun, Mehmet Burhanettin, and Banu Tanriover. 2016. An investigation on nuclear energy policy in Turkey and public perception. In *EPJ Web of Conferences*. Paris: EDP Sciences, vol. 128, p. 5001.

da Mata, Jonatas F., Rieder O. Neto, and Amir Z. Mesquita. 2017. Comparison of the Performance, Advantages and Disadvantages of Nuclear Power Generation Compared to Other Clean Sources of Electricity. Available online: https://inis.iaea.org/collection/NCLCollectionStore/_Public/49/009/49009723.pdf?r=1 (accessed on 5 May 2022).

DeCanio, Stephen. J. 2009. The political economy of global carbon emissions reductions. *Ecological Economics* 68: 915–24. [CrossRef]

Deutch, John, Ernest Moniz, Stephen Ansolabehere, Michael Driscoll, Paul Gray, John Holdren, Paul Joskow, Richard Lester, and Neil Todreas. 2003. The Future of Nuclear Power. An MIT Interdisciplinary Study. Available online: http://web.mit.edu/nuclearpower (accessed on 5 May 2022).

Driscoll, Michael J., and Pavel Hejzlar. 2005. Reactor physics challenges in Gen-IV reactor design. *Nuclear Engineering and Technology* 37: 1–10.

EIA (Energy Information Administration). 2006. CANDU Reactors. Available online: http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/china/candu.htmls (accessed on 5 May 2022).

Elliott, David, ed. 2016. *Nuclear Or Not?: Does Nuclear Power Have a Place in a Sustainable Energy Future?* New York: Springer.

Erdogdu, Erkan. 2007. Nuclear power in open energy markets: A case study of Turkey. *Energy Policy* 35: 3061–73. [CrossRef]

Fiore, Karine. 2006. Nuclear energy and sustainability: Understanding ITER. *Energy Policy* 34: 3334–41. [CrossRef]

Flynn, James, James Chalmers, Doug Easterling, Roger Kasperson, Howard Kunreuther, C. K. Mertz, Alvin Mushkatel, David K. Pijawka, Paul Slovic, and Lydia Dotto. 1995. *One Hundred Centuries of Solitude. Redirecting America's High-Level Nuclear Waste Policy*. Boulder: Westview Press.

Forsberg, Charles W. 2009. Sustainability by combining nuclear, fossil, and renewable energy sources. *Progress in Nuclear Energy* 51: 192–200. [CrossRef]

Franco, Sainu, Venkata Ravibabu Mandla, and K. Ram Mohan Rao. 2017. Urbanization, energy consumption and emissions in the Indian context. A review. *Renewable & Sustainable Energy Reviews* 71: 898–907.

Gunay, Defne, and Emre Iseri. 2017. Unexpected Persistence Amidst Enlargement Stasis: Usages of Europe in Turkey's Nuclear Energy Debate. *South European Society and Politics* 22: 101–19. [CrossRef]

Halkos, George, and Argyro Zisiadou. 2019. Examining the natural environmental hazards over the last century. *Economics of Disasters and Climate Change* 3: 119–50. [CrossRef]

Halkos, George, and Argyro Zisiadou. 2020a. An overview of the technological environmental hazards over the last century. *Economics of Disasters and Climate Change* 4: 411–28. [CrossRef]

Halkos, George, and Argyro Zisiadou. 2020b. Is investors' psychology affected due to a potential unexpected environmental disaster? *Journal of Risk and Financial Management* 13: 151. [CrossRef]

Halkos, George. 1996. Incomplete information in the acid rain game. *Empirica* 23: 129–48. [CrossRef]

Halkos, George. 2003. Environmental Kuznets Curve for sulfur: Evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics* 8: 581–601. [CrossRef]

Halkos, George. 2013. Exploring the economy–environment relationship in the case of sulphur emissions. *Journal of Environmental Planning and Management* 56: 159–77. [CrossRef]

Hamacher, Thomas, and John Sheffield. 2004. *Development of Fusion Power: What Role Could Fusion Power Play in Transitional and Developing Countries*. IPP Garching (with support from EFDA) and Joint Institute for Energy, 2004-04, IIP-Report Max-Planck-Institutfür Plasmaphysik. Available online: https://pure.mpg.de/rest/items/item_2136776/component/file_2136775/content (accessed on 5 May 2022).

Hansen, Kenneth. 2019. Decision-making based on energy costs: Comparing levelized cost of energy and energy system costs. *Energy Strategy Reviews* 24: 68–82. [CrossRef]

Heal, Geoffrey. 2009. Reflections—The economics of renewable energy in the United States. *Review of Environmental Economics and Policy* 4: 139–54. [CrossRef]

Hedenus, Fredrik, Azar Christian, and Daniel J. A. Johansson. 2010. Energy security policies in EU-25—The expected cost of oil supply disruptions. *Energy Policy* 38: 1241–50. [CrossRef]

Hempelman, Louis Henry, Clarence C. Lushbaugh, and George L. Voel. 1979. *What Has Happened to the Survivors of the Early Los Alamos Nuclear Accidents?* LA-UR-79-2802. Los Alamos: Los Alamos Scientific Laboratory.

Hench, Larry L., David E. Clark, and Alan B. Harker. 1986. Nuclear waste solids. *Journal of Materials Science* 21: 1457–78. [CrossRef]

Hopkins, Andrew. 2001. Was three mile island a 'Normal Accident'? *Journal of Contingencies and Crisis Management* 9: 65–72. [CrossRef]

Hossain, Emran, Rej Soumen, Saha Sourav Mohan, Onwe Joshua Chukwuma, Nwulu Nnamdi, Bekun Festus Victor, and Amjad Taha. 2022. Can energy efficiency help in achieving carbon-neutrality pledges? A developing country perspective using dynamic ARDL simulations. *Sustainability* 14: 7537. [CrossRef]

Immonen, Anne, and Maria Kopsakangas-Savolainen. 2022. Capturing Consumers' Awareness and the Intention to Support Carbon Neutrality through Energy Efficient Consumption. *Energies* 15: 4022. [CrossRef]

Irfan, Mohd, and Krishnendu Shaw. 2017. Modeling the effects of energy consumption and urbanization on environmental pollution in South Asian countries: A nonparametric panel approach. *Quality & Quantity* 51: 65–78.

Iwata Hiroki, Okada Keisuke, and Sovannoeun Samreth. 2010. Empirical study on the environmental Kuznets curve for CO_2 in France: The role of nuclear energy. *Energy Policy* 38: 4057–63. [CrossRef]

Jaworowski, Zbigniew. 2010. Observations on the Chernobyl Disaster and LNT. *Dose-Response* 8: 148–71. [CrossRef] [PubMed]

Jebli Mehdi Ben, Youssef Slim Ben, and Ilhan Ozturk. 2016. Testing environmental Kuznets curve hypothesis: The role of renewable and non-renewable energy consumption and trade in OECD countries. *Ecological Indicators* 60: 824–31. [CrossRef]

Jewell, Jessica. 2011. Ready for nuclear energy?: An assessment of capacities and motivations for launching new national nuclear power programs. *Energy Policy* 39: 1041–55. [CrossRef]

Kagel, Alyssa, Diana Bates, and Karl Gawell. 2005. *A Guide to Geothermal Energy and the Environment*; Washington: Geothermal Energy Association. Available online: www.geo-energy.org (accessed on 5 May 2022).

Kebede, Abraham Alem, Theodoros Kalogiannis, Van Mierlo Joeri, and Maitane Berecibar. 2022. A comprehensive review of stationary energy storage devices for large scale renewable energy sources grid integration. *Renewable and Sustainable Energy Reviews* 159: 112213. [CrossRef]

Keeney, Ralph L., and Detlof von Winterfeldt. 1994. Managing nuclear waste from power plants. *Risk Analysis* 14: 107–30. [CrossRef]

Kim, Taek K. 2013. Gen-IV Reactors. In *Nuclear Energy*. New York: Springer, pp. 175–201.

Kok, Besir, and Hüseyin Benli. 2017. Energy diversity and nuclear energy for sustainable development in Turkey. *Renewable Energy* 111: 870–77.

Korkmaz, Ozan, and Bihrat Önöz. 2022. Modelling the Potential Impacts of Nuclear Energy and Renewables in the Turkish Energy System. *Energies* 15: 1392. [CrossRef]

Kumar, Dinesh, Alam Syed Bahauddin, Ridwan Tuhfatur, and Cameron S. Goodwin. 2021. Quantitative risk assessment of a high power density small modular reactor (SMR) core using uncertainty and sensitivity analyses. *Energy* 227: 120400. [CrossRef]

Kurt, Ünal. 2014. The fuzzy TOPSIS and generalized Choquet fuzzy integral algorithm for nuclear power plant site selection—A case study from Turkey. *Journal of Nuclear Science and Technology* 51: 1241–55. [CrossRef]

Liu, Zhitao, and Jihong Fan. 2014. Technology readiness assessment of small modular reactor (SMR) designs. *Progress in Nuclear Energy* 70: 20–28. [CrossRef]

Lorusso, Pierdomenico, Serena Bassini, Del Nevo Alessandro, Di Piazza Ivan, Giannetti Fabio, Tarantino Mariano, and Marco Utili. 2018. GEN-IV LFR development: Status & perspectives. *Progress in Nuclear Energy* 105: 318–31.

Lutze, Werner. 1988. Silicate glasses. In *Radioactive Waste Form for the Future*. Edited by Lutze Werner and Rodney C. Ewing. Amsterdam: Elsevier Science Publishers B.V., pp. 1–159.

Macfarlane, Allison M., and Marvin Miller. 2007. Nuclear energy and uranium resources. *Elements* 3: 185–92. [CrossRef]

Malenfant, Richard E. 1996. *Lessons Learned from Early Criticality Accidents*. No. LA-UR–96-1659. Los Alamos: Los Alamos National Lab.

Managi, Shunsuke, and Dabo Guan. 2017. Multiple disasters management: Lessons from the Fukushima triple events. *Economic Analysis and Policy* 53: 114–22. [CrossRef]

Mastrocinque, Ernesto, F. Javier Ramírez, Honrubia-Escribano Andrés, and Duc T. Pham. 2020. An AHP-based multi-criteria model for sustainable supply chain development in the renewable energy sector. *Expert Systems with Applications* 150: 113321. [CrossRef]

McLaughlin, Thomas P., Shean P. Monahan, Norman L. Pruvost, Vladimir V. Frolov, Boris G. Ryazanov, and Victor I. Sviridov. 2000. *A Review of Criticality Accidents*. 2000 Revision, LA-13638. Los Alamos: Los Alamos National Laboratory.

Menyah, Kojo, and Yemane Wolde-Rufael. 2010. CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. *Energy Policy* 38: 2911–15. [CrossRef]

Mourmouris, John C., and Constantinos Potolias. 2013. A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy* 52: 522–30. [CrossRef]

Moysich, Kirsten B., Ravi J. Menezes, and Arthur M. Michalek. 2002. Chernobyl-related ionising radiation exposure and cancer risk: An epidemiological review. *The Lancet Oncology* 3: 269–79. [CrossRef]

Murty, K. Linga, and Indrajit Charit. 2008. Structural materials for Gen-IV nuclear reactors: Challenges and opportunities. *Journal of Nuclear Materials* 383: 189–95. [CrossRef]

NEA. 2005. *Projected Costs of Generating Electricity: Update 2005*. Paris: Publication of the Nuclear Energy Agency (NEA) to the Organisation for Economic Cooperation and Development (OECD) and International Energy Agency (IEA).

NEA. 2008. *Nuclear Energy Outlook*. No. 6348. Paris: OECD.

Norio, Okada, Tao Ye, Yoshio Kajitani, Peijun Shi, and Hirokazu Tatano. 2011. The 2011 eastern Japan great earthquake disaster: Overview and comments. *International Journal of Disaster Risk Science* 2: 34–42. [CrossRef]

Nuttall, William J. 2005. *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power*, 1st ed. New York: Taylor and Francis.

OECD. 2001. *Nuclear Power in the OECD, Organisation for Economic Cooperation and Development (OECD) and International Energy Agency (IEA)*. Paris: OECD.

Oettingen, Mikolaj. 2018. Criticality analysis of the Louis Slotin accident. *Nuclear Engineering and Design* 338: 92–101. [CrossRef]

Omri, Anis, Nejah Ben Mabrouk, and Amel Sassi-Tmar. 2015. Modeling the causal linkages between nuclear energy, renewable energy and economic growth in developed and developing countries. *Renewable and Sustainable Energy Reviews* 42: 1012–22. [CrossRef]

Ozcan, Mustafa, Mehmet Yildirim, and Semra Ozturk. 2016. Generation expansion planning scenarios to reduce natural gas dependency of Turkey. *Energy Exploration and Exploitation* 34: 244–61. [CrossRef]

Paramati, Sudharshan Reddy, Avik Sinha, and Eyup Dogan. 2017. The significance of renewable energy use for economic output and environmental protection: Evidence from the Next 11 developing economies. *Environmental Science and Pollution Research* 24: 13546–60. [CrossRef]

Perrow, Charles. 1981. Normal accident at three mile island. *Society* 18: 17–26. [CrossRef]

Prohorovs, Anatolijs. 2022. Russia's war in Ukraine: Consequences for European countries' businesses and economies. *Journal of Risk and Financial Management* 15: 295. [CrossRef]

Rahman, Md Mustafizur, Abayomi Olufemi Oni, Gemechu Eskinder, and Amit Kumar. 2020. Assessment of energy storage technologies: A review. *Energy Conversion and Management* 223: 113295. [CrossRef]

Ramana, Muvva V. 2018. Technical and social problems of nuclear waste. *Wiley Interdisciplinary Reviews: Energy and Environment* 7: e289. [CrossRef]

Reddy, B. Sudhakara, and Gaudenz B. Assenza. 2009. The great climate debate. *Energy Policy* 37: 2997–3008. [CrossRef]

Rowinski, Marcin Karol, Timothy John White, and Jiyun Zhao. 2015. Small and Medium sized Reactors (SMR): A review of technology. *Renewable and Sustainable Energy Reviews* 44: 643–56. [CrossRef]

Rybach, Ladislaus. 2003. Geothermal energy: Sustainability and the environment. *Geothermics* 32: 463–70. [CrossRef]

Sauga, Michael. 2008. The Atomic Ageenters a New Dawn. Spiegel Online International. July 11. Available online: http://www.spiegel.de/international/world/0,1518,565132,00.htmls (accessed on 6 May 2022).

Schiermeier, Quirin, Tollefson Jeff, Scully Tony, Witze Alexandra, and Oliver Morton. 2008. Energy alternatives: Electricity without carbon. *Nature* 454: 816–24. [CrossRef]

Shafiei, Sahar, and Ruhul A. Salim. 2014. Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: A comparative analysis. *Energy Policy* 66: 547–56. [CrossRef]

Sirin, Selahattin Murat. 2010. An assessment of Turkey's nuclear energy policy in light of South Korea's nuclear experience. *Energy Policy* 38: 6145–52. [CrossRef]

Sokolski, Henry. 2010. The High and Hidden Costs of Nuclear Power. *Policy Review* 162: 53–68.

Song, Bing, and Peter Hall. 2020. Densification of biomass and waste plastic blends as a solid fuel: Hazards, advantages, and perspectives. *Frontiers in Energy Research* 8: 58. [CrossRef]

Stefanovsky, Sergey V., Sergey V. Yudintsev, Reto Gieré, and Gregory R. Lumpkin. 2004. Nuclear waste forms. *Geological Society, London, Special Publications* 236: 37–63. [CrossRef]

Ilhan, Talinli, Emel Topuz, and Mehmet Uygar Akbay. 2010. Comparative analysis for energy production processes (EPPs): Sustainable energy futures for Turkey. *Energy Policy* 38: 4479–88. [CrossRef]

Kenta, Tanaka, and Shunsuke Managi. 2016. Impact of a disaster on land price: Evidence from Fukushima nuclear power plant accident. *The Singapore Economic Review* 61: 1640003. [CrossRef]

Temurçin, Kadir, and Alpaslan Aliağaoğlu. 2003. Nuclear energy and reality of nuclear energy in Turkey in the light of discussions. *Turkish Journal of Geographical Sciences* 1: 25–39.

Tokimatsu, Koji, Jun'ichi Fujino, Konishi Satoshi, Ogawa Yuichi, and Kenji Yamaji. 2003. Role of nuclear fusion in future energy systems and the environment under future uncertainties. *Energy Policy* 31: 775–97. [CrossRef]

Topal-Namli, Hanife, and Suat Sean Namli. 2014. Nuclear Power in Turkey: Pros and Cons. Available online: http://westeastinstitute.com/journals/wp-content/uploads/2015/03/3.Hanife-Topal-Namli-JWEIBE.pdf (accessed on 7 May 2022).

Toth, Ferenc L., and Hans-Holger Rogner. 2006. Oil and nuclear power: Past, present, and future. *Energy Economics* 28: 1–25. [CrossRef]

Vaillancourt, Kathleen, Maryse Labriet, Loulou Richard, and Jean-Philippe Waaub. 2008. The role of nuclear energy in long-term climate scenarios: An analysis with the World-TIMES model. *Energy Policy* 36: 2296–307. [CrossRef]

Vassilev, Stanislav V., Christina G. Vassileva, and Vassil V. Vassilev. 2015. Advantages and disadvantages of composition and properties of biomass in comparison with coal: An overview. *Fuel* 158: 330–50. [CrossRef]

Vujić, Jasmina, Ryan M. Bergmann, Škoda Radek, and Marija Miletić. 2012. Small modular reactors: Simpler, safer, cheaper? *Energy* 45: 288–95. [CrossRef]

Wang, Yuefa, Zhongxi Chao, De Chen, and Hugo A. Jakobsen. 2011. SE-SMR process performance in CFB reactors: Simulation of the CO_2 adsorption/desorption processes with CaO based sorbents. *International Journal of Greenhouse Gas Control* 5: 489–97. [CrossRef]

Weber, William J., Rodney C. Ewing, C. Austen Angell, George W. Arnold, Alastair N. Cormack, Jean Marc Delaye, David L. Griscom, Linn W. Hobbs, Alexandra Navrotsky, David L. Price, and et al. 1997. Radiation effects in glasses used for immobilization of high-level waste and plutonium disposition. *Journal of Materials Research* 12: 1948–78. [CrossRef]

Yim, Man-Sung, and K. Linga Murty. 2000. Materials issues in nuclear-waste management. *Jom* 52: 26–29. [CrossRef]

Zhao, Shujie, Duan Weichao, Zhao Dongfeng, and Qingbin Song. 2022. Identifying the influence factors of residents' low-carbon behavior under the background of "Carbon Neutrality": An empirical study of Qingdao city, China. *Energy Reports* 8: 6876–86. [CrossRef]

Zolberg, Vera L. 1998. Contested remembrance: The Hiroshima exhibit controversy. *Theory and Society* 27: 565–90. [CrossRef]