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Environment, Climate Change and Nuclear Energy

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Abbreviations

AEC	Atomic Energy Commission
CCS	Carbon Capture and Storage
CTBT	Comprehensive Nuclear-Test-Ban Treaty
EU	European Union
FOF	Force-on-Force
GHG	Greenhouse Gas
Gt	Gigaton
HLW	High-level waste
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
ILW	Intermediate-level waste
INES	International Nuclear and Radiological Event Scale
IPCC	Intergovernmental Panel on Climate Change
JCPOA	Joint Comprehensive Plan of Action
kWh	Kilowatt hour
LLW	Low-level waste
Mt	Metric tons
NATO	North Atlantic Treaty Organization
NDC	National Determined Contribution
NDCs	Nationally Determined Contributions
NEA	Nuclear Energy Association
NEA	Nuclear Energy Agency
NISA	Nuclear and Industrial Safety Agency
NPP	Nuclear Power Plant
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NRC	Nuclear Regulatory Commission
NWFZ	Nuclear Weapons Free Zone
OECD	Organization for Economic Co-Operation and Development
PTBT	Partial Test Ban Treaty
RCPs	Representative Concentration Pathways
TEPCO	Tokyo Electric Power Company

TWh	Terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
USSR	Union of Soviet Socialist Republics
WANO	World Association of Nuclear Operators
WEO	World Economic Outlook

Introduction

Energy demand has increased in recent decades because of gradually increasing energy needs of our society. Urbanization, industrialization and population growth are only some of the reasons rising energy demand. There are also some rapidly developing states with great energy needs. Because of its importance in our lives it is necessary to ensure energy security.

However, the combustion of fossil fuels used for the energy production burdens impacts of climate change. Climate change is mainly caused by human activities. The energy industry is one of the greatest causes of air pollution because of CO_2 emissions, water pollution and global warming. Extreme weather events take place because they are the result of climate change. In addition, many people suffer from health problems caused by pollution.

In order to prevent negative health and environmental impacts of climate change, alternative energy resources have to be exploited. Nuclear energy is one of these alternative solutions. It is a form of clean energy with low greenhouse gas emissions. Except from the environmental challenges, nuclear energy can cope the challenge of energy security. It can produce a great amount of energy by a small amount of fuel. It is claimed that its low fuel cost makes nuclear energy competitive, although it has high investment costs.

Despite its advantages, great concerns delay the expansion of nuclear energy. There are significant risks for the environment and public health in case radiation is released because of a nuclear accident. The three great nuclear accidents (Three Mile Island, Chernobyl, Fukushima Daiichi) had devastating impacts and defined public acceptance of nuclear energy. Nuclear waste management is also one of the problems that has to be settled. Furthermore, the proliferation of nuclear weapons causes fear to public opinion. Concerns for international peace and stability rise. There are contradictory opinions whether their proliferation benefits or not international community. These concerns affect nuclear energy expansion because of fear and stress they cause.

In the present dissertation the position of nuclear energy in the energy mix is examined, as clean energy policies are adopted. In chapter 1, the issue of energy security and the impacts of climate change in our lives are examined. In chapter 2, there are references to uses of nuclear energy, its economy and its position in global energy mix. In chapter 3, the advantages and disadvantages of nuclear energy by an environmental aspect, are mentioned. In chapter 4, the greatest concerns of the nuclear energy expansion, thus nuclear accidents, nuclear weapons and nuclear terrorism, are described. Finally, in chapter 5, the example of China is presented, in order to examine if nuclear energy is a preferable alternative energy resource.

<u>Chapter 1</u>: The importance of energy

1.1 Energy in our lives

Energy has a defining role in our lives. Since the beginning of existence of human species energy has a crucial position. It defines our survival, our development and our safety. Many domains of our societies are dependent on energy, such as economy and politics. The use of electricity is determining, as almost all sectors of our everyday lives are based on it, such as transportation, heating of buildings, communication, trade, health and mechanized agriculture.

Since the prehistorical era people tried to ensure their survival by using wood and stone. The progress of technology and the skills that human had developed, led to the discovery of new fuels (e.g. lignite, coal, oil, natural gas, renewable, nuclear) and new ways of producing energy. However, the increasing energy demand of our society has affected energy security. Energy security is a mixture of concerns. The policies adopted in order to prevent potential disruptions in energy production, supply and use, have to take into consideration the numerous impacts of energy systems in climate change. These energy security agendas have to set the protection of environment as one of their main priorities.

1.2 The issue of Energy Security

The role of energy in people's lives is undoubtedly vital. Because of the Industrial Revolution, energy demand was increased and its usage was determining in many functions of our societies, such as transportation, trade, agriculture, electricity generation and heating of buildings.

During World War I and II, the significance of oil as a transport fuel in military sector was realized. It started replacing coal and it was globally understood how essential the oil supply security was. The term of energy security was identified with the term national security. The diversification of suppliers, the reduction of fuel imports and the expansion of domestic production were only some of the tactics used after the end of wars, in order to ensure security of fuels.

In the 1970s the problem of dependence of many industrialized societies on imported resources arose because of oil embargoes. The concentration of oil resources in specific geographic locations and the volatility of prices were affected by the embargoes. Energy security became a high priority issue in the political agenda of each industrialized state. The IEA was established in 1974 as a response in the oil embargo. Its main goal was the protection of importing countries in case of an unexpected disruption of its supply.

As energy security was combined with oil security, the research of alternative energy resources and fuels became urgent. Natural gas and nuclear energy were some of the alternative strategies that states examined and started using so as to ensure their energy needs. Although these strategies were essential, new problems arose. Natural gas resources are concentrated in specific geographic areas and construction of pipeline networks was necessary in order to supply it in other countries.

As a result, importing countries were dependent on their suppliers. Potential political instability and tension among transit countries, suppliers and importing countries could affect energy security. The Russia-Ukraine gas dispute in the beginning of 21th century is such an example. In the territory of Ukraine many gas pipelines are located. Because of political disputes between Russia and Ukraine, countries of Western Europe lost their gas supplies. In the case of nuclear energy, the security of transmission and generation systems were central problems. Nuclear accidents led to lack of public acceptance of civilian nuclear energy. In addition, the high capital costs of nuclear power plants, their age, their safety issues and the concerns about producing nuclear weapons, influenced the term of security.

Another significant historic event affecting energy security is the collapse of Soviet Union in 1991. It became clear that there was need for the fuel exporting countries to be protected. If their economies wanted to remain viable, then they should not try to have stable revenues only by energy exports. This was the result of their economic models. They based their economies only on exports of their fuel resources and, finally, they could not be antagonistic in any other sector of the economy. Russia is a characteristic example of the resource curse phenomenon after the collapse of Soviet Union.

As a result of all the above mentioned, it is understood that energy security includes many different aspects and it is not easy to have a common term universally. In every different time period, its concept differs and it always has a central role in geopolitics. Importing and exporting countries are not dependent, but interdependent. On the one hand, importers are interested in having continuous flows of energy in affordable prices. On the other hand, exporting states desire their fuels to be demanded in the global market in prices able to cover production and transfer costs, so as to develop their economies.

Nowadays, energy security does not include only economic concerns, the volatility of prices and the issue of energy demand. It is a critical matter and there is a great need to define it, as many developing countries, such as China and India, have risen their energy demand in order to cover their energy needs. The concentration of resources in specific regions, such as Russia and Middle East, and the dependence of importing states by them cause insecurity, which is combined with geopolitics of energy. Every potential dispute in their territories or the disruption of positive international relations can be harmful for the energy supply in several other dependent importing countries. In such case, the fear of tensions and conflicts arise. Furthermore, possible terrorist attacks to energy infrastructure cause fears for the vulnerability of the energy systems and energy supply. The same fear exists as far as it concerns extreme natural events, which cause enormous disasters to the energy infrastructure (e.g. the Hurricane Katrina in the USA). Another issue of energy security is the development of the technology needed so as to avoid these disruptions or to confront them in a short time and the facilitation of the energy access.

Finally, climate change is also one of the reasons why more and more extreme natural events take place, causing damages to energy supply chains and in energy infrastructure. The protection of environment is one of the basic pillars of energy policies globally. One of the main targets of energy sector recent decades is the exploitation of clean forms of energy and it will remain as such. This is the reason why discussions for the expansion of nuclear energy are so intense.

1.3 Definition of Energy security

Energy security develops many different aspects during decades. This is one of the main reasons why there is not a specific definition of it in literature. The fact that each state has different needs and unequal level of energy resources affect the dimensions which have to be examined, so as to approximate the substance of energy security.

One of the most general accepted definition in energy security is the 4As definition: availability, affordability, accessibility, acceptability. According to J. Ren and B.K. Sovacool «*Availability relates to the physical or geological existence of energy resources and the ability for a given community or country to secure those resources*. *Affordability includes economic considerations such as price, externalities, equity, and price stability*. *Acceptability refers to social and environmental concerns associated with energy production and use. Accessibility relates to geopolitical elements and the robustness of resilience of the entire system*».[1] They claim that each one of them is separated in metrics and all these dimensions have to exist simultaneously in order to achieve energy security.

The perspectives of energy security, according to Cherp and Jewell, are robustness, sovereignty and resilience. They are linked to the policies adopted depending on the type of disruption. «*Robustness is focused on protection from disruptions originating from predicable and "objective" natural, technical, and economic factors such as resource scarcity, rapid rise of demand, aging of infrastructure, or rising energy prices*. *Sovereignty is focused on protection from disruptions originating from intentional actions of various actors (such as unfriendly political powers and overly powerful market agents). Sovereignty implies the ability to control the behavior of energy systems and is often linked to much-discussed "energy independence". Resilience is focused on protection from disruptions originating from less predictable factors of any nature, such as political instability, game changing innovations, or extreme weather events».*[2]

Based on the rapid changes in technology, energy needs, political agendas, economy and environment, the substance of term "energy security" will continue to change during next decades.

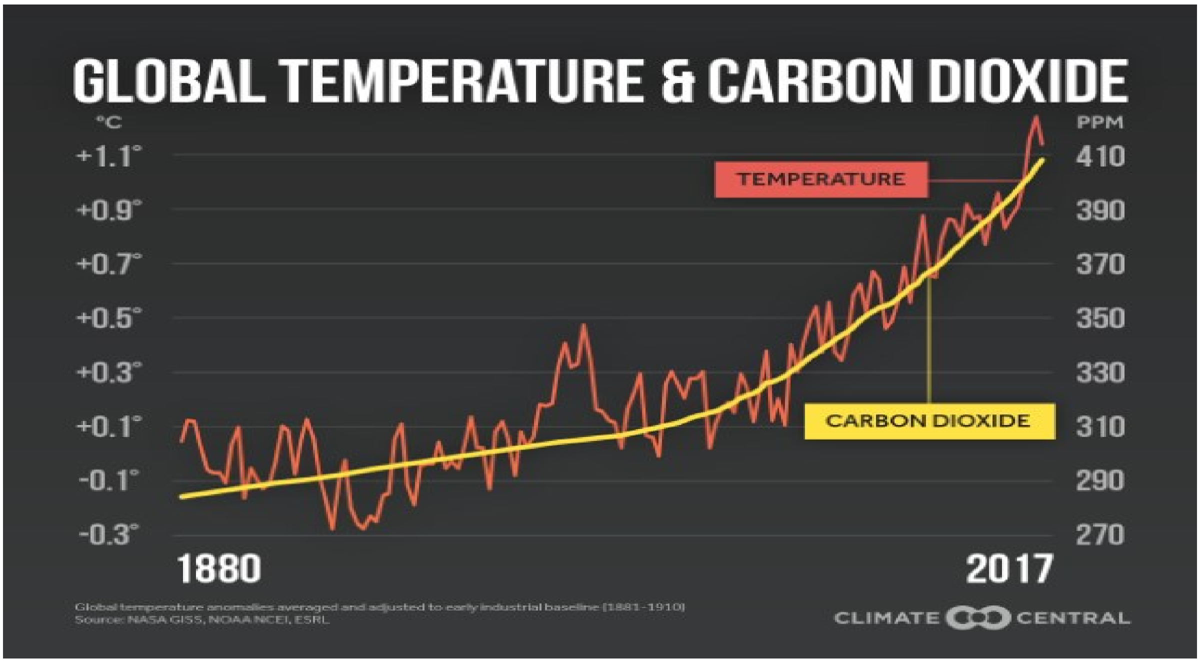
[1] Ren J., Sovacool B. (2014). Quantifying, measuring, and strategizing energy security: Determining the most meaningful dimensions and metrics. *Energy*, *Volume 76*, p. 841. https://www.sciencedirect.com/science/article/abs/pii/S0360544214010482

[2] Cherp, A. et al. (2012). Energy and security. In T. B. Johansson, N. Nakicenovic, & A. Patwardan (Eds.), Global Energy Assessment: Toward a Sustainable Future, Cambridge University Press, p. 330. https://portal.research.lu.se/ws/files/5735037/4239056.pdf

1.4 The Climate Change

One of the central issues that our societies have to deal with during last decades is the climate change problem. The high concentration of greenhouse gas emissions in the atmosphere causes negative impacts on Earth's temperature. It is commonly accepted that a significant percentage of the problems caused because of global warming is a result of human activities. In order to cover rising energy demand, the greenhouse gas emissions are increased because of the combustion of fossil fuels[3]. Many subsequent consequences of global warming set in danger our ecosystems and our lives. States try to cooperate and adopt policies which will decrease gas emissions and will prevent further temperature rises.

Figure 1:



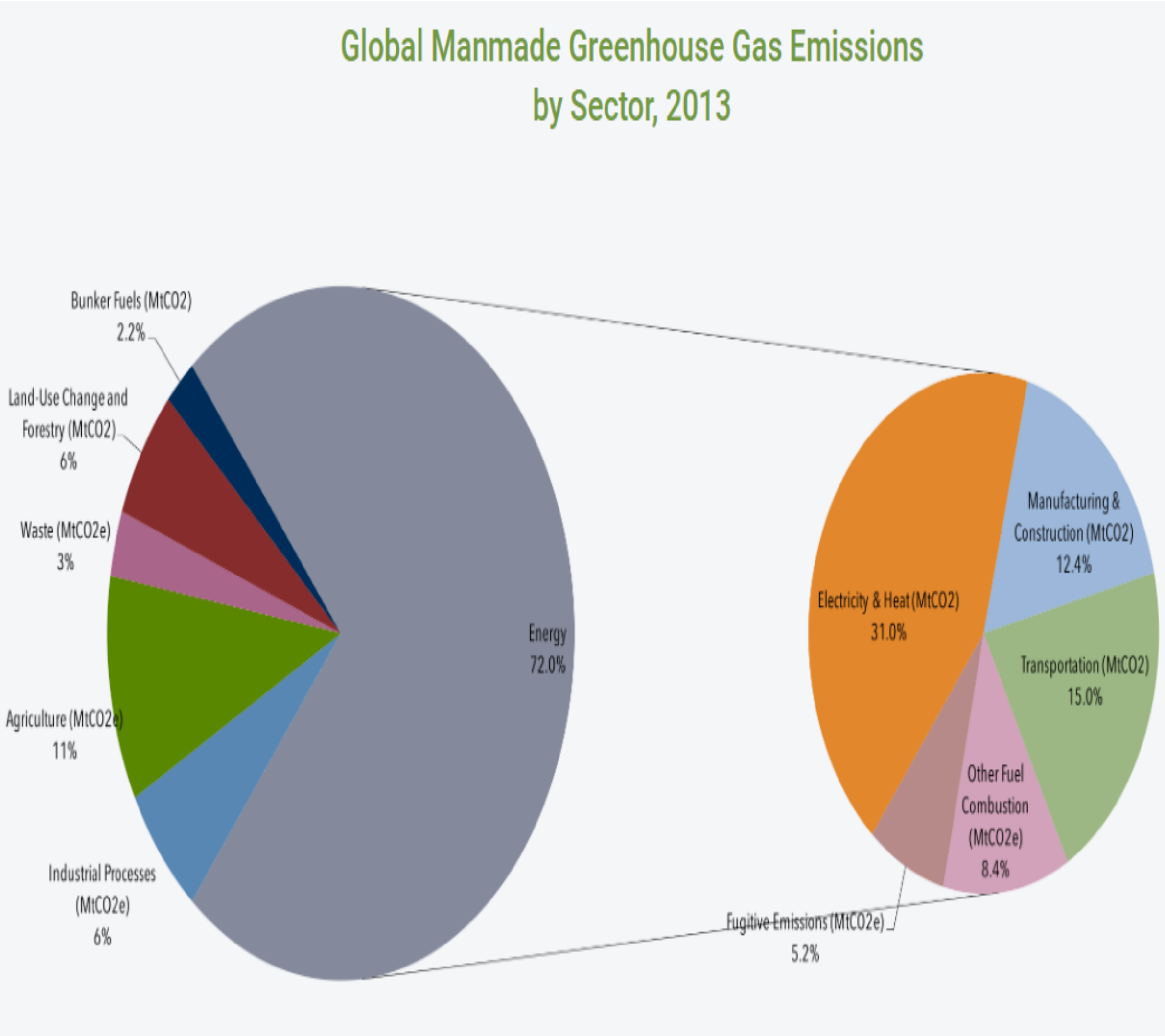
Source: Climate Central (2018). Retrieved from https://www.climatecentral.org/gallery/graphics/co2-and-rising-global-temperatures

Although there is a part of humanity that claims that global warming is not a result of people's activities but an effect of sun radiation and other natural activities in the atmosphere, human activities have a determining role. The combustion of fossil fuels (oil, coal, natural gas) in order to produce energy is the main source of greenhouse gas emissions. According to the World Resources Institute, in 2013, 72% of greenhouses gas emissions globally were produced by energy sector. The electricity and heating sector covered 31% of the GHG emissions and transportation sector produced 15% of emissions (Figure 2).

[3] Henderson M. R. et al. (2018). Climate Change in 2018: Implications for Business, Harvard University Business, p. 1-3. https://www.hbs.edu/environment/Documents/climate-change-2018.pdf

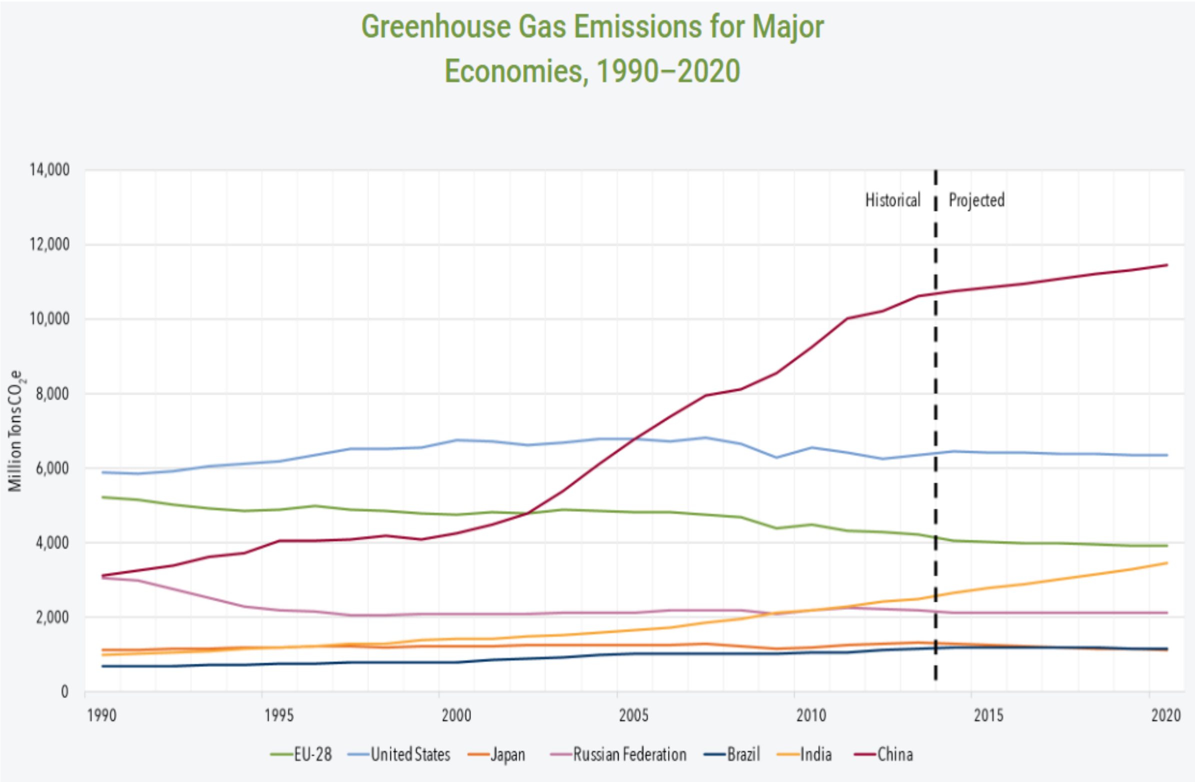
Greenhouse gas emissions of each country differ depending on its energy mix. Developing countries prefer using coal because of its low price. As a result, they produce greater amounts of emissions. Contrary to these facts, developed countries with higher energy demands may have less or the same gas emissions with the past because of their advanced technology. In addition, countries with higher energy demands, such as China, have increased their percentages of emissions in comparison with other developed countries (Figure 3).

Figure 2:



Source: Climate Analysis Indicators Tool (World Resources Institute, 2017). Retrieved from https://www.c2es.org/content/international-emissions/

Figure 3:



Source: World Energy Outlook (International Energy Agency, 2016). Retrieved from https://www.c2es.org/content/international-emissions/

The rising GHG concentration in the atmosphere has several subsequent impacts in environment. First of all, the amounts of snow on mountains and the ice of the poles have diminished. As a result, the level of the sea has risen because of ice melting. Many coastal areas, cities and small islands, such as Fiji Islands in the Pacific Ocean, are in danger of sinking or losing a part of their territories. Population of these areas will be forced to migrate. Almost 143 million people will become climate immigrants because of sea-level rise and other effects of climate change[4].

In 2018, the IPCC published a special report concerning the impacts of global warming in case humanity could manage to reduce global warming to 1.5º C compared to 2º C. Because of global warming, the temperature of oceans is higher, affecting marine ecosystems. Coastal resources are decreased and the productivity of fisheries is affected. Several marine species extinct or migrate destabilizing marine ecosystems. If the high confident scenario is successful (1.5° C), the rise of sea level would be lower than predicted and the impacts in ecosystems would be less catastrophic.[5]

[4] Parker L., (2018). 143 Million People May Soon Become Climate Migrants, *National Geographic*. https://www.nationalgeographic.com/news/2018/03/climate-migrants-report-world-bank-spd/

[5] IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate

In addition, because of higher temperature, the evaporation of water increases causing droughts or greater rates of rainfalls, shifting the rainfall patterns across the world and causing extreme weather conditions. Many areas suffer from extreme weather conditions and natural disasters, such as typhoons, floods, droughts and fires, causing numerous of deaths and disasters. For example, the percentages of rainfalls had been decreased and droughts began in California in late 2011[6].

Agriculture is also influenced. Food production is combined with the availability of water, as agriculture is threatened in case of water shortage. The water is also vital for people's lives. Food and water insecurity rise. Therefore, numerous people migrate in order to ensure their survival. Water scarcity and food insecurity may also lead to conflicts[7].

Climate change has also negative impacts on human health. Many people die because of heat waves and suffer from heat stress. For instance, many elderly and sick people died in 2003 during the heatwave in Europe[8]. Because of air pollution, many people suffer from cardiovascular and respiratory diseases which may be fatal. In addition, because of polluted water or because of its scarcity, many infectious diseases may be expanded, as hygiene is compromised. Most developing countries will be more vulnerable to these negative impacts because they lack the necessary technological know-how and organization of public health systems[9].

In order to prevent these negative impacts and reduce them in the future, states try to adopt energy policies which set the decrease of greenhouse gas emissions as their main targets. In 1995, some countries started negotiating and two years later they adopted the Kyoto Protocol. Developed country parties were legally bound to set emission reduction targets and succeed them in a specific timetable.[10]

In 2015, Parties of the UNFCCC signed Paris agreement in order to combat climate change and intensify all the necessary efforts for a sustainable, low carbon future. The main aim is to keep the temperature rise below 2º C above pre-industrial levels and to limit the temperature increase even further to 1,5º C. Furthermore, countries must increase their ability to deal with impacts of climate change. In order to achieve them, technology framework has to be enhanced, states need to invest and

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change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, p. 9-12. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

[6] USGCRP, (2017). Chapter 7: Precipitation Change in the United States. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. https://science2017.globalchange.gov/chapter/7/

[7] Henderson M. R. et al. (2018). Climate Change in 2018: Implications for Business, Harvard University Business, p. 3-5. https://www.hbs.edu/environment/Documents/climate-change-2018.pdf

[8] World Health Organization (2018). Climate Change and Health. https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

[9] UN, UN Chronicle. The Health Effects Of Global Warming: Developing Countries Are The Most Vulnerable. https://www.un.org/en/chronicle/article/health-effects-global-warming-developing-countries-are-most-vulnerable

[10] UN. (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change. https://unfccc.int/resource/docs/convkp/kpeng.pdf

developed countries have to help the developing states in order to accomplish their goals[11].

As a consequence, we have to use alternative ways of producing energy. They have to be friendly to the environment, with lower carbon emissions, economically feasible and public acceptable. The main aim of the present dissertation is to examine the possibilities nuclear energy to increase its percentage in electricity production, despite the serious concerns and its effects on society and the international community. The example of China will be presented.

[11] UN. (2015). Paris Agreement. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

Chapter 2: Nuclear Energy

Nuclear energy is one of the ways to produce electricity. It is the energy existing in the nucleus of an atom. The particles of the nucleus are bounded together by forces of great strength. Nuclear energy can be obtained from nuclear decay and nuclear fission.

2.1 The History of Nuclear Energy

The development of nuclear energy is the result of scientific and technological efforts over the last 100 years. Based on their development and realizing the importance of energy in our lives, there were attempts of commercializing it.

Since the middle of 1940s the attention was mainly focused on the construction of an atomic bomb. In 1939 fission was discovered by Hahn and Strassmann in Berlin. An enormous amount of energy are released during fission, when atoms of uranium are forced to break apart. As a result, a self-sustaining chain reaction is produced, releasing great amounts of energy. This discovery is the basis of the development of the atomic bomb, a weapon of mass destruction, which is one of the central arguments against the use of nuclear energy. Atomic bombs were exploded in 1945 to Hiroshima and Nagasaki. Later, in the 1950s it was the first time the President of the USA proposed the development of peaceful uses of nuclear power. Since then, civil nuclear energy development began[12].

2.2 Uses of nuclear energy

The basic purpose of using nuclear energy is the electricity production. Electricity demand, especially in industrial societies, arises from a number of sectors, such as industry, transportation, domestic and commercial use. It has to be continuous in order to cover the demand in a 24-hour period. As a result, there is need of constructing power stations able to cover the uninterruptable demand. The prices of electricity must also be affordable for consumers.

The conventional fuels are less eco-friendly and they are scarce. Alternative fuels are necessary. Uranium is one of the options able to cover this lack, as it is abundant and it is located in more politically stable countries, in contrary to fossil fuels. New technologies are also developed for the extraction of uranium by seawater[13]. Great amounts of this element may be mined and treated, but after its processing, only a small amount of it can produce electricity able to cover the energy demand of a city. As it is highly available, it is more reliable than renewable energy (wind, solar). Only the countries which are members of the Nuclear Non-Proliferation Treaty (NPT) are

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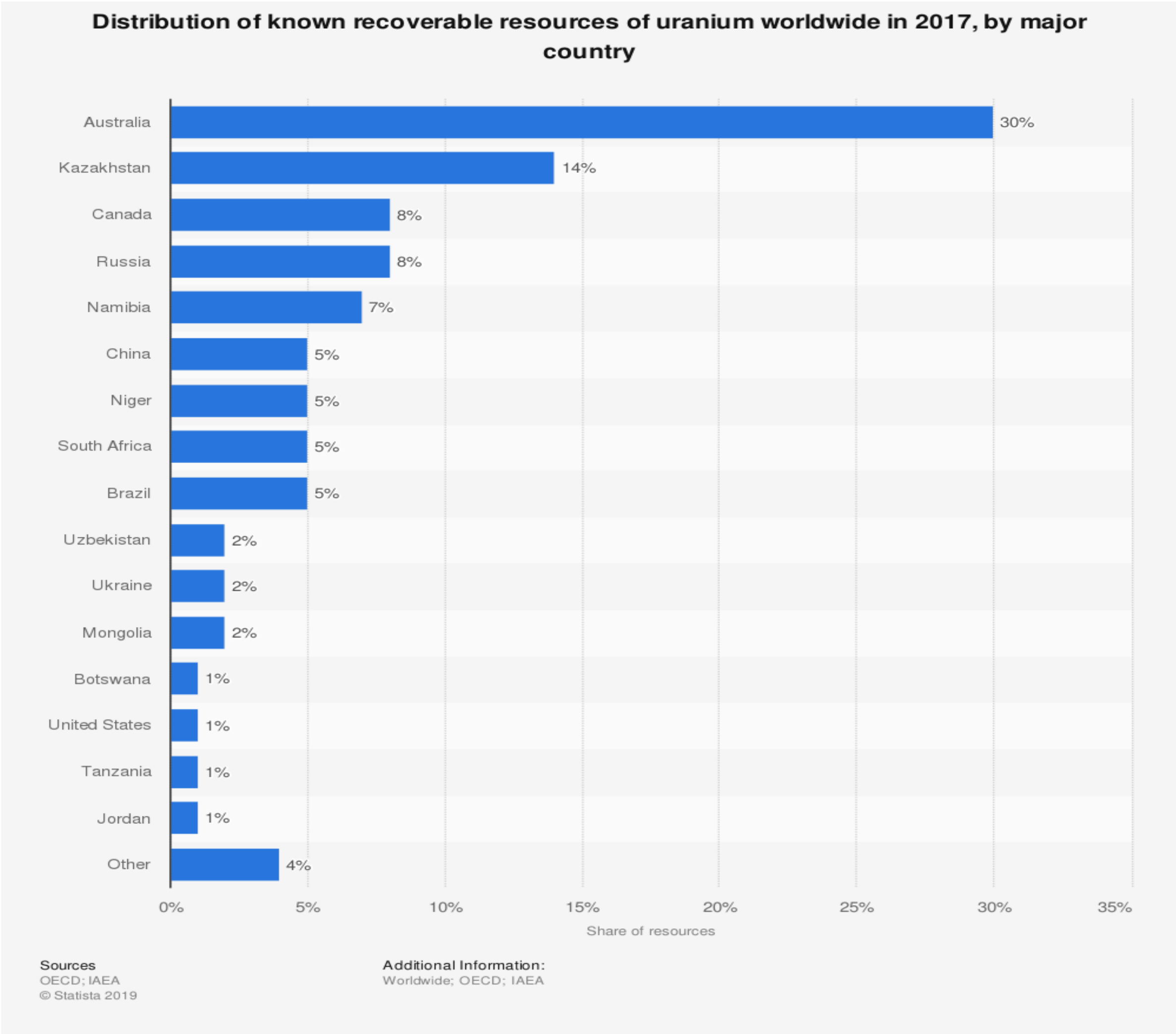
[12] World Nuclear Association (2019). Outline History of Nuclear Energy. https://www.world-nuclear.org/information-library/current-and-future-generation/outline-history-of-nuclear-energy.aspx

[13] Pavela L. G., Budua R. A., Morarua E. D. (2017). Optimization of energy mix - Nuclear power and Renewable Energy for low emissions energy source a benefit for generations to come. *Sustainable Solutions for Energy and Environment, Conference, EENVIRO 2016*. *Energy Procedia, Volume 112,* p. 412-417. https://www.sciencedirect.com/science/article/pii/S1876610217312171

allowed to import uranium or plutonium (nuclear fuels), so as to control the spread of nuclear weapons.

Figure 4:



Source: OECD, IAEA (Statista, 2019). Retrieved from https://www.statista.com/statistics/652996/distribution-of-global-uranium-resources-by-country/

However, nuclear energy is used for other reasons too, such as medical reasons, naval propulsion, the production of military weapons etc.

- Production of electricity:

Because of rising energy demand the amount of electricity consumed per capita has been increased. The future energy demand will be determined by politics, economy, technology and the level of population growth. It is going to be increased because of urbanization in several areas suffering from energy poverty, such as Africa. In addition, energy needs of developing countries, such as China and India, have been increased rapidly. There are efforts our societies to become more energy efficient based on the development of technology and the adoption of relative policies. Nuclear energy seems to take advantage of this development.

Nuclear reactors which are used for the production of energy are improved and they can produce greater amounts of electricity from a smaller amount of fuel. Nowadays, several types of reactors exist, depending on the nuclear reaction they control, their cooling agent, their fuel, etc.[14]. Nuclear power produces electricity in a more stable way rather than renewable energy, in which the amount of energy produced is determined by external factors (e.g. solar, wind).

Almost 450 nuclear power plants generate around 10% of the world's electricity. These nuclear power plants operate in 30 countries. There are also countries which plan to start nuclear programs. Most of them do not have the necessary expertise, so they rely on other countries. Russia and China have a leading role in financing and fuelling these emerging nuclear countries[15]. There are countries where a significant percentage of electricity is generated by nuclear power plants. For instance, France produces almost two thirds of electricity from nuclear power plants and it exports an amount of it in neighbouring countries. It is the leading user of nuclear energy in Europe[16].

- Nuclear-powered ships:

Nuclear energy is suitable for vessels which travel to the sea for a long period of time without having the ability to be refuelled and for submarine propulsion.

The efforts for the marine propulsion started in the 1940s and the first nuclear-powered submarine was putted in the sea in 1955 by the USA. Britain, France, Russia and China were making efforts to develop their own navy. While the first efforts of the USA were successful, the Soviet Navy had a number of serious accidents with reactors damages, which caused release of radiation. During Cold War, USA and Russia had constructed numerous of nuclear submarines and vessels, most of which are now scrapped because of weapon reduction programs[17].

There are also civil vessels, especially in the Russian Arctic, which are technically and economically essential, as the difficulty in refuelling and the level of the power required so as to break the thick ice are beyond the capabilities of conventional ice-breakers. Because of international policy goals for lower CO_2 emissions, there are possibilities of extending the use of marine nuclear propulsion[18].

[14] Bodancky D. (2004). Chapter 2: Nuclear Power Development, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 33-42.

[15] World Nuclear Association (2019), Emerging Nuclear Energy Countries. https://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx

[16] Murray R. L., Holbert E. K. (2019), Chapter 24 - Nuclear Energy Future, *Nuclear Energy An Introduction to the Concepts, Systems, and Applications of Nuclear Processes* - *8th Edition*. Butterworth-Heinemann. p. 471-503. https://www.sciencedirect.com/science/article/pii/B9780128128817000241

[17] Hore-Lacy I. (2007), 6- Other Nuclear Energy Applications, *Nuclear Energy in the 21st Century*, The World Nuclear University Press, p. 100-103.

[18] World Nuclear Association (2019), Nuclear-Powered Ships. https://www.world-nuclear.org/information-library/non-power-nuclear-applications/transport/nuclear-powered-ships.aspx

- <u>Space:</u>

Nuclear energy can also be used in space exploration. The radioisotope thermoelectric generators are a long-term source of electricity which can operate without disruption for many year even under difficult conditions.

In the past, such fission reactor had been used by both the USA and Russia. After a gap period, there is a revival for the use of nuclear energy in space missions[19].

- <u>Medical Treatments:</u>

Recent decades the radiation is used as a medical therapy in specific diseases, such as cancer. The doses of radiation has to be precise depending on the case. There are still several concerns in medical cycles. However, undoubtedly the contribution of radiation in this sector is positive[20].

- <u>Agriculture:</u>

In order to fight against food poverty, food irradiation is a way of extending the life of food and killing bacteria which cause food-borne diseases. In countries where this method is applied, regulations are introduced in order to allow it. However, concerns of consumers for the reliability of the method has limited its application. Furthermore, via a specific technique (Sterile Insect Technique), there is the ability of controlling the population of insects, in order to use less insecticide and protect the agriculture[21].

- <u>Desalination:</u>

Water scarcity is a significant problem in our societies. The ability of turning seawater into potable water is crucial in order to cover water needs. Nuclear seawater desalination plants may desalinate huge amounts of water because of their large amount of energy. Such nuclear desalination plants exist for many years in Kazakhstan, India and Japan, and new reactors are going to be constructed in Australia, Argentina, Brazil, etc.[22]

2.3 The economics of Nuclear Energy

The financial factor is extremely important in comparing alternative generating systems. Regarding nuclear energy, the price of fuel, the investment costs, the operational costs and the costs which incur after a potential cessation of a nuclear plant are determining for the decision to invest in a nuclear power plant. There are also some costs that are internalised in nuclear power, while they are external in other energy industries.

Investment costs include costs of construction, design, relative licenses and decommissioning. Decommissioning costs are related to all the necessary procedures

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[19] Supra note 17

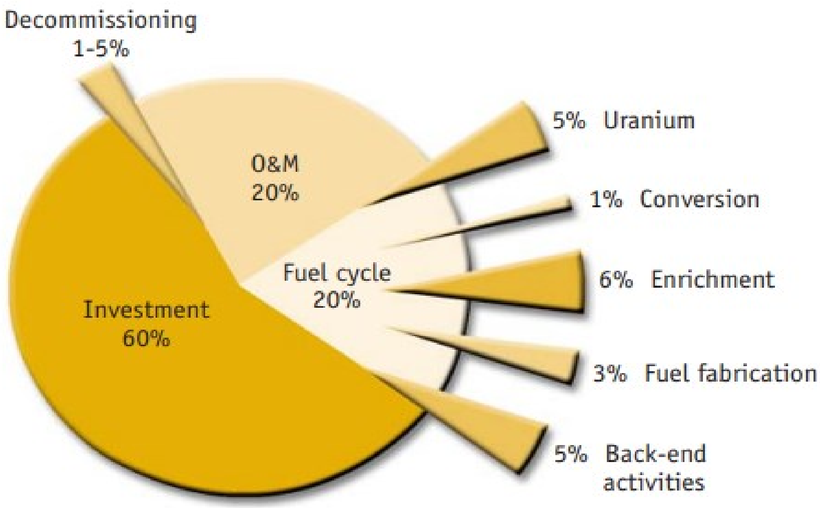
[20] Murray L. R. (2008), 18 – Useful Radiation Effects, *Nuclear Energy: An Introduction to the Concepts, Systems, and Applications of Nuclear Processes, 6th Edition*, USA, Butterworth-Heinemann, p. 269-288.

[21] Supra note 20

[22] World Nuclear Association (2019), Desalination. https://www.world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-desalination.aspx

in order to shut down a nuclear power plant according to the relevant policies. They also manage radioactive waste. These costs are amortised in a time period of 20-25 years. Fuel costs are all the costs related to fuel cycle, the purchase and conversion of uranium, fuel fabrication, spent fuel conditioning and disposal or recycling. Finally, operation and maintenance costs are the costs which are not considered in the previous two categories and they are related to health, safety, staff training and security. According to NEA[23], fuel costs represent only 20% of the costs of nuclear-generated electricity. Investment costs are very high. They are usually fixed after construction of power plants and only operation and maintenance costs can be an opportunity for reduction of costs. In coordination with the development of technology and the improving of the efficiency, nuclear power plants can remain competitive.

Figure 5: Typical nuclear electricity generation cost breakdown



Source: NEA (2003), Retrieved from https://www.oecd-nea.org/pub/nuclearenergytoday/3595-nuclear-energy-today.pdf

As the investment for the construction of a nuclear power plant is long-term, the financial risk is important. It is vulnerable to long-term changes in the market, which may affect revenues. In addition, legal regulations are very strict and they can reduce the investment flexibility.

Another important issue is the externalisation of costs in nuclear electricity generation. Many costs are internalised, as it is provided by regulations (e.g. radiation, decommissioning, waste management costs, safety measures). As a result, nuclear

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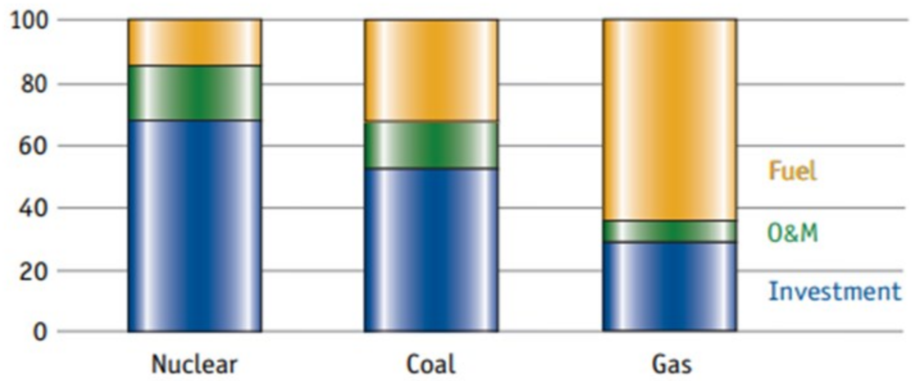
[23] NEA (2003), Chapter 7 – The Economics of Nuclear Energy, *Nuclear Energy Today,* France, OECD Publication, p. 59-63. https://www.oecd-nea.org/pub/nuclearenergytoday/3595-nuclear-energy-today.pdf

electricity generation does not have many external costs.[24] In case such costs were increased, then its competiveness would be affected.

In order to estimate the cost of such projects, important studies for its feasibility have to take place by a technological, financial, environmental and political perspective. In comparison with the investment costs of coal or gas fired plants, NPPs are more expensive and complex, because of the use of special materials, their backup control equipment and their long construction time (a typical duration of the construction of an NPP is almost 7 years). Thus, they are risky investment proposition. However, they remain competitive because of their health and environmental costs in contrary to other energy industries (e.g. coal).

Figure 6: Breakdown of representative generation costs



Source: NEA. *Projected Costs of Generating Electricity* (Paris: OECD, 1998). Average of values for Canada, France, Japan, Spain and the United States.

Retrieved from https://www.oecd-nea.org/pub/nuclearenergytoday/3595-nuclear-energy-today.pdf

2.4 Nuclear Energy in the Energy Mix

In energy sector several industries are included. Coal, oil, natural gas are the most widespread fuels used to produce electricity. In addition, renewable energy industries (solar, wind, hydropower) are developed, as they are low emitter technologies and they are promoted by several environmental policies. Nuclear energy is another form of clean energy, which is not used in many countries for electricity production, because of its expensive projects and several public concerns for environment and public health.

Increasing energy needs is the reason why so many industries are developed for electricity production. Possible disruptions in energy chain make the existence of alternative energy sources necessary. Furthermore, the extraction of fossil fuels becomes more difficult and expensive and their combustion causes several health and

[24] NEA (2007). 8 - External Costs and Multiple Criteria Decision Analysis, *Risks and Benefits of Nuclear Energy,* OECD, p. 63-73. https://www.oecd-nea.org/ndd/pubs/2007/NDD_2007_%206242-risks_benefits_nuclear_energy.pdf

environmental consequences. In addition, eco-friendly environmental policies promote low carbon technology so as to reduce impacts of climate change in our lives. Each country decides which energy technology will adopt according to its needs, its financial condition, the availability of fuels, its geographical position and the available technologies. By mixing the previous mentioned technologies, countries ensure the security of supply and the well-being of their citizens. The disadvantage of a technology can be replaced by another technology.

Nuclear energy has already an important role in the energy mix globally, as 10.2% of the electricity is produced from nuclear reactors. According to the IEA, hydro produces 16.3% and renewable energy 6.6% of world electricity production (Figure 7). Renewable energy sources may not be always able to supply the quantities of electricity needed and problems still exist in energy storage, however their technology is developed and they are promoted by energy policies as they have higher levels of public acceptance. Most of nuclear energy electricity production takes place to North America, Western and Central Europe and Asia[25]. The amount of electricity produced to each state by nuclear energy is presented in Figure 9.

There are countries, such as Romania, that have managed to create a stable energy mix, producing electricity from different industries. Other countries have managed to be energy independent, as they are not dependent on imports of oil and natural gas and they produce electricity by their nuclear power plants, such as France. However, despite the fact that France is the largest net exporter of electricity in the world because of low cost of nuclear power generation, it intends to reduce the share of nuclear energy to 50%, so as to prevent its dependency on nuclear power and it will replace it with renewable power resources[26]. As a result, nuclear energy has to coexist with other low carbon industries in order to balance energy demand.

[25] World Nuclear Association (2019). Nuclear Power in the World Today. https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx
[26] EIA (2016). France Overview. https://www.eia.gov/beta/international/analysis.php?iso=FRA

Figure 7:

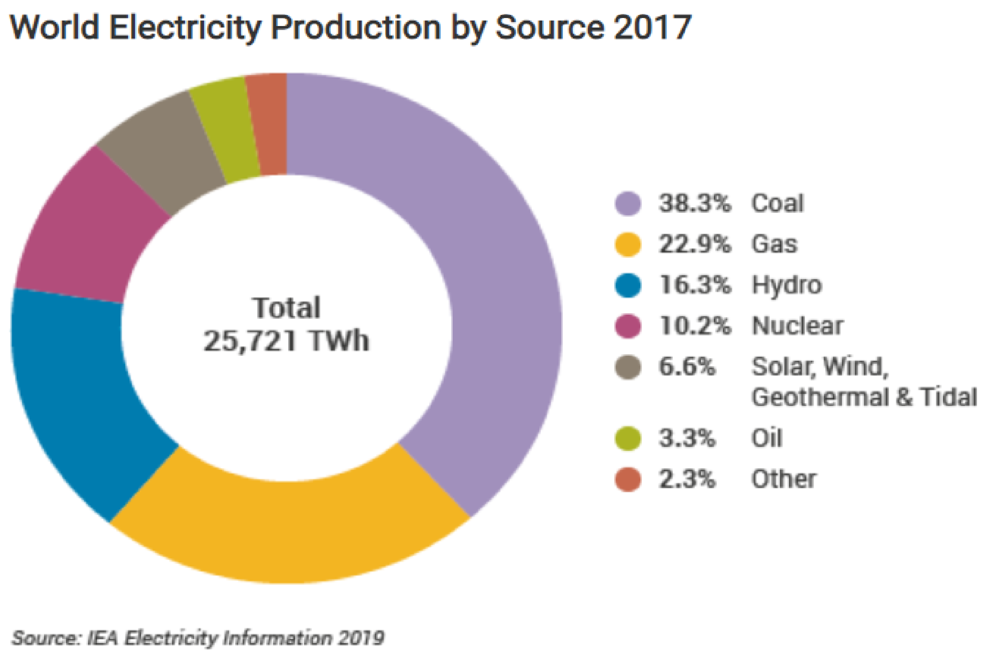


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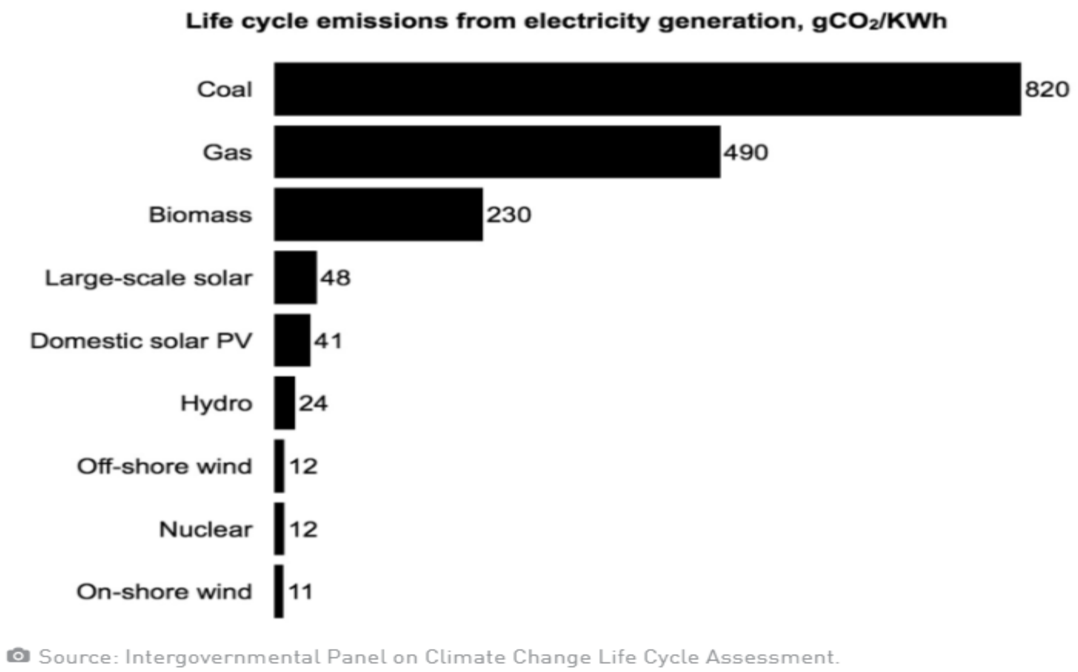
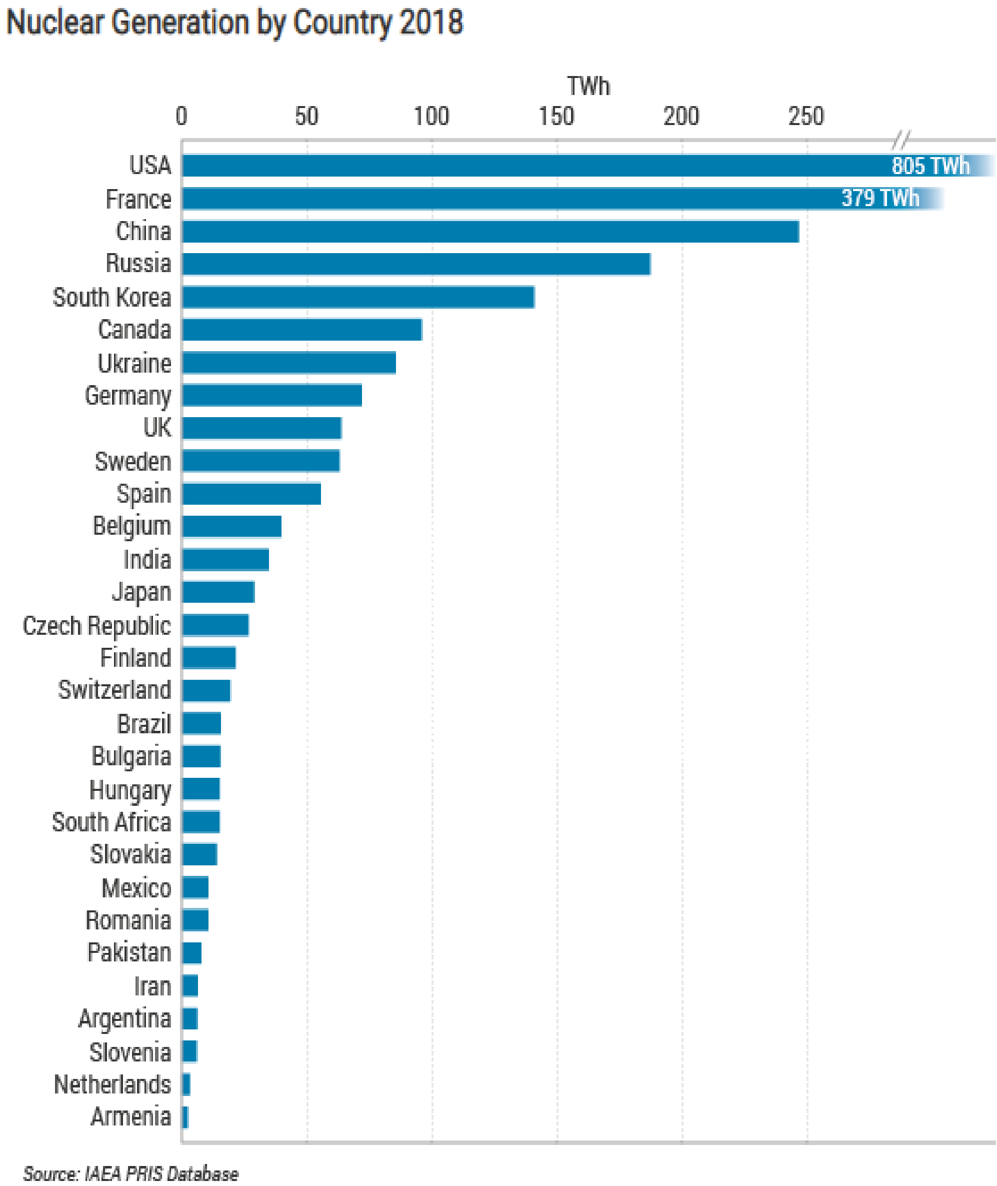
Figure 8:



Retrieved from http://energyforhumanity.org/briefings/carbon-emissions/lifecycle-carbon-emissions-of-electricity-generation-sources/

Figure 9:



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Chapter 3: Nuclear Energy and Environment

3.1 Emissions of Greenhouse gases (GHGs)

Since the international community realized the disasters and the risks that climate change causes, policies and efforts available to minimize its negative impacts were adopted. An example of such policies is the adoption of Paris Agreement in 2015. Its main purpose is the limitation of GHG emissions in the atmosphere in order to limit global warming and mitigate the results of climate change.

As reported in the IAEA Publication of 2016, according to several scenarios for the changes of temperature the global average surface temperature will exceed 1,5°C since the end of century. Only one of these RPCs has a positive prediction that global temperature will not exceed 1,5°C until the end of century, as it includes assumptions that strict policies for the mitigation of GHG emissions will be adopted[27]. Taking into consideration these scenarios, the future of humans, environment and natural resources of Earth is not optimistic.

Because of global warming ice melting is increased, the level of the sea is risen, territories are covered by water and population will be forced to migrate from coastal areas which will be sunk. In addition, water security will be affected as the amount of potable water will be decreased because of extreme heating. As a result, food insecurity will be caused as agricultural productivity will be reduced. It will also be affected by extreme weather events, droughts and floods, which are outcomes of global warming. Damages in energy infrastructure and energy supply chain may also be caused by such weather conditions. Furthermore, the terrestrial and coastal ecosystems will be damaged by the results of global warming. Human lives are vulnerable and they are threatened by all these consequences of global warming. Several health problems are results of lack of water, food insecurity, extreme heat and GHG emissions. The possibilities of a war to start is high in areas where the previous mentioned problems are presented. People will try to ensure their survival destabilizing national and global security. The least developed countries have to deal with more risks and barriers in order to mitigate the negative results of climate change caused by GHG emissions. Their ability to adapt these challenges is limited.

The GHG emissions have a central role in global warming. The period 1983-2012 is, according to scientists, the warmest three decades of the last 1400 years[28]. As a result, glaciers were shrunk rapidly, the temperature of the sea and its level were risen, water cycle changed causing extreme weather conditions. Emissions affect and aggravate the ozone depletion, which is one of the reasons of increasing global warming. The increase of emissions was dramatic after the Industrial Revolution. According to the IAEA Publication of 2018 the increase of CO_2 concentration since

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[27] IAEA (2016), Chapter 2: The Need for Nuclear Power, *Climate Change and Nuclear Power 2016* (online), p. 6-15. https://www-pub.iaea.org/MTCD/Publications/PDF/CCANP16web-86692468.pdf

[28] IAEA (2018), Chapter 2: The Climate Change Challenge, *Climate Change and Nuclear Power 2018*, (online), p. 12-14. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

1750 was insignificant (from 260 ppm to 280 ppm) and it was a result of natural causes. But emissions were almost doubled, as they were over 400 ppm since 2016 because of the increase of anthropogenic emissions. The results were similar in other GHG emissions at the same period of time. There was an increase of 150% at CH_4 concentration and an increase of 20% in N_2O concentration.[29] These GHG emissions (CH_4, N_2O) exist in lower amounts than CO_2 in the atmosphere, however their impacts in global warming are significant[30].

The increase of emissions was the consequence of domination of fossil fuels in sectors of energy and global economy. Coal and oil were available globally, as they were easy to transfer and they had high density, but they have high levels of emissions released. Until the 1950s only hydroelectricity was the low carbon alternative. After that period natural gas, nuclear energy and renewable energy were developed. Climate change was not the primary reason of searching for alternative fuels during that period of time. It was necessary to ensure energy security, as most states were dependent on oil. If energy dependency was not important in global political and economic agenda, there would be possibilities CO_2 emissions not to be reduced, as the role of fossil fuels would remain central in energy production.

Under these circumstances, it is obvious that there is necessity of adopting international policies which could lead to possible reduction of these problems. In 2015, the Paris Agreement was a landmark agreement in order to deal with climate change, as it is universal and legally binding. Nations have to undertake several efforts so as to cope with climate change, to adapt its effects and adopt policies and measures which will enhance the present and future situation of the environment. It is a long term agreement which includes strategies that cover environmental, economic and social issues of climate protection. It emphasizes the importance of using low carbon technology in order to limit global average temperature below 2^{o} C above pre-industrial levels. All parties have to adopt domestic measures, to provide information for their NDCs so as to preserve the transparency needed. Adaptation is one of the main goals of the agreement at a national level and it may be supported by international cooperation of states, as it is a common global challenge. There is need of improving technology, know-how and efforts of states and non-state actors so as to succeed the goals set. Low carbon investments and investments in energy efficiency are important for the accomplishment of targets[31].

According to the IAEA Publication of 2018 "*Nuclear power, along with hydroelectricity and wind power, emits the lowest quantity of GHGs per kW·h of generation, while emissions are substantially higher for fossil technologies, including*

[29] Supra note 28

[30] IAEA (2018), Chapter 4: The Role of Nuclear Power in Climate Change Mitigation, *Climate Change and Nuclear Power 2018,* (online), p. 44-47.
https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

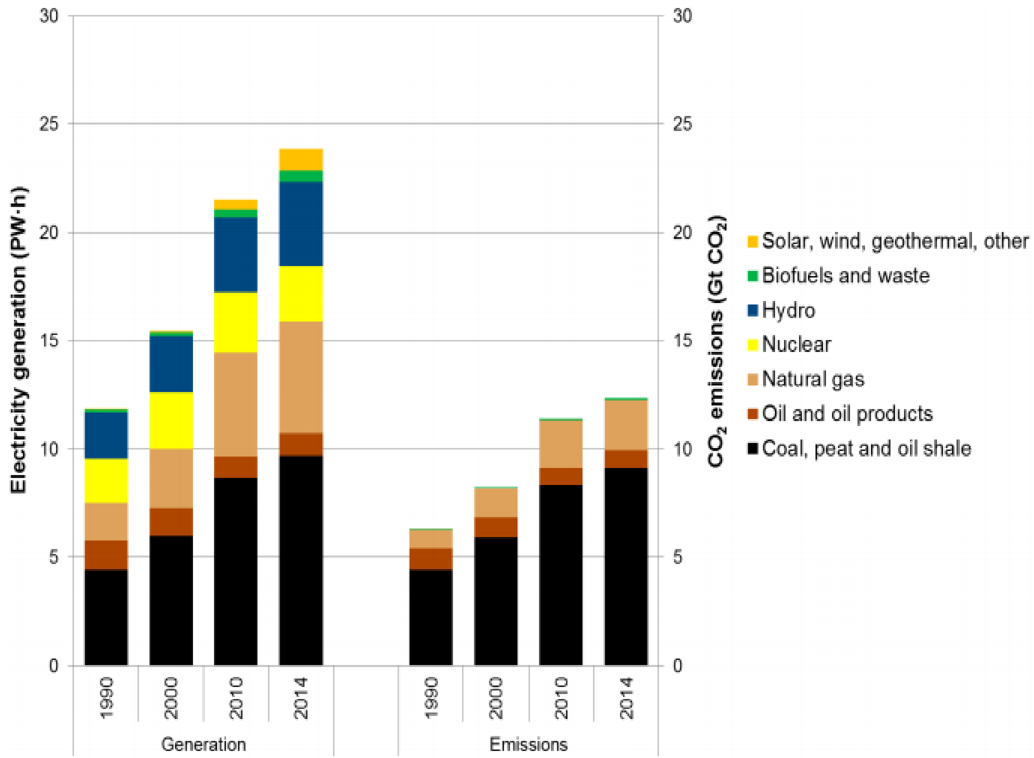
[31] UN Climate Change. What is the Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/what-is-the-paris-agreement

plants equipped with CCS facilities."[32]The amount of emissions of nuclear power plants are not stable, but they differ depending on the uranium quality, its enrichment and the stage of the nuclear cycle fuel. As it is mentioned in the IAEA Publication of 2018 *"The nuclear fuel cycle includes the 'front end', i.e. preparation of the fuel, the 'service period' in which fuel is used during reactor operation to generate electricity, and the 'back end', i.e. the safe management of spent nuclear fuel including reprocessing and reuse and disposal. If spent fuel is 35 not reprocessed, the fuel cycle is referred to as an 'open' or 'once-through' fuel cycle; if spent fuel is reprocessed, and partly reused, it is referred to as a 'closed' nuclear fuel cycle"*[33]. No emissions are released during operation as uranium is not burned, in contrast with coal. On the other hand, in previous stages of nuclear fuel chain (e.g. mining, transport, fuel fabrication, enrichment of uranium, reactor construction) GHG are released, as fossil fuels are used. The level of emissions are also affected in case the operating lifetime is extended, as they are emitted for a longer period of time. However, the amount of emissions released is not comparable with the emissions of fossil fuels. They are significantly lower.

According to the Publication of IAEA in 2018, 68 Gt CO_2 emissions were avoided to be emitted thanks to nuclear power stations from 1970 to 2015. In 1970 it avoided less than 0.1 Gt CO_2. In 1980 it was increased to 0.62 Gt CO_2 and reached 1.69 Gt CO_2 in 1990. In 2000 it reached 2.12 Gt CO_2 and it decreased to 1.95 Gt CO_2 in 2015. Based on these results, in combination with rising energy demand, the positive influences of nuclear energy in the limitation of greenhouse gases in the atmosphere are undeniable[34]. Despite the important percentage of electricity that is produced using nuclear energy, only a small number of emissions are released, minimizing the total number of emissions that would have been emitted if another fossil fuel was used for electricity production (Figure 11). As a result, nuclear energy seems to be one of the solutions to decrease GHG emissions and prevent numerous diseases caused by them.

[32] IAEA (2018), Chapter 3: Focusing on the Energy Sector, *Climate Change and Nuclear Power 2018* (online), p. 34. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf
[33] IAEA (2011). The Nuclear Fuel Cycle, Information Booklet, IAEA, Austria.
[34] Supra note 30

Figure 10: Global electricity generation and related CO_2 emissions by fuel in 1990-2014



Source: OECD International Energy Agency (2017), CO2 Emissions from Fuel Combustion 2017, OECD Publishing, Paris. Retrieved from https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf, p.33

Figure 11:

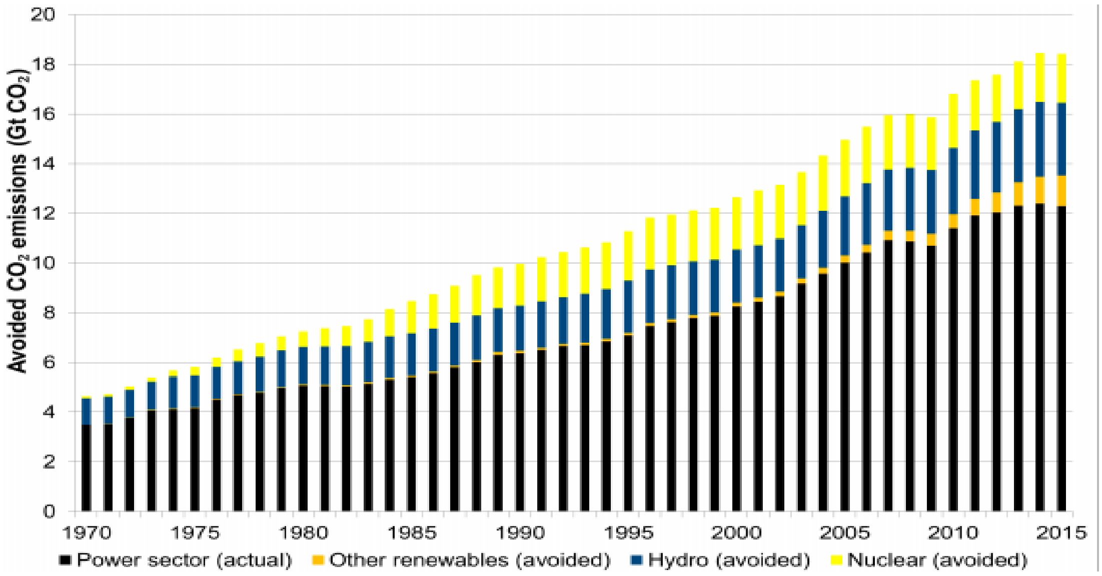


FIG. 17. Global CO_2 emissions from the electricity sector and emissions avoided by using three low carbon generation technologies. The black parts of the columns indicate the actual CO_2 emissions from the global electricity sector in a given year, while the total heights of columns represent the estimated total emissions if fossil fuels alone had been used to supply the same amount of electricity. Coloured sections of the bars represent the emissions avoided by the use of nuclear energy, hydropower and other renewables. Source: IAEA calculations based on data in Ref. [21]. Note: Gt CO_2 — gigatonnes of carbon dioxide.

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3.2 The importance of water in nuclear energy

Water is a vital natural resource for our planet and every form of life. It covers 70% of earth's surface, mostly in oceans, but there are also smaller amounts of water in lakes, rivers, groundwater, glaciers in Antarctica and Greenland. It has an important role in many sectors of our lives, such as health, transportation, agriculture and production of energy.

Most impacts of climate change and global warming affect water and change "water cycle". Because of higher temperatures the evaporation of water is increased and extreme weather events influence the ecosystems and every sector which is dependent on water.

Water has a central role in energy production, as they are interdependent. It is used in transportation, extraction of natural resources and in several stages of production of energy. As a result, energy sector consumes great amounts of water and causes several forms of water pollution. These negative impacts are increased because of population growth and high energy demand in a global level. The amount of available water and water quality needed is a significant actor in energy production[35]. According to the IEA *"The inter-dependencies between energy and water are set to intensify in the coming years, as the water needs of the energy sector rise. The energy sector is responsible for 10% of global water withdrawals, mainly for power plant operation as well as for production of fossil fuels and biofuels. In our main scenario, these requirements grow over the period to 2040: water withdrawals for the energy sector rise by less than 2% to reach over 400 billion cubic metres (bcm), while the amount of water consumed (i.e. that is withdrawn but not retuned to a source) increases by almost 60% to over 75 bcm. In the power sector there is a switch to advanced cooling technologies that withdraw less water, but consume more. A rise in biofuels demand pushes up water use and greater deployment of nuclear power increases both withdrawal and consumption levels"*[36]. According to the IEA, nuclear power plants consumed 28% of global water withdrawals in 2014, because they have high cooling needs and the heat they produce cannot be released in the atmosphere directly (Figure 12). The technology used for the production of electricity (nuclear, renewable, hydroelectricity etc) deters the amount of water needed. Energy policies have to be very careful and take into consideration the decrease of freshwater so as to choose the preferable power generation technology.

Water is one of the main pillars in electricity production to nuclear power plants. Water is vaporized in the nuclear reactor to pressurized steam and it is led to multiple turbines which produce electricity. Then, steam is cooled and it is send back to the nuclear reactor, where the procedure is repeated. In addition, cooling water is travelling from natural reservoirs (lake, rivers etc.) to the condenser in order to cool process water and then it is released back to the reservoir. This is the reason why nuclear power plants are constructed near rivers, lakes, oceans. As it is mentioned in World Nuclear Association, according to a sitting study in UK, these power plants have to be located within 2 km of abundant water and based on IAEA figures *"45% of nuclear plants use the sea for once-through cooling, 15% use lakes, 14% rivers, and 26% use cooling towers"*[37]. Cooling water returns to the environment and only a small amount of it is vaporized. However, the temperature of the water released is high and it affects aquatic ecosystems. There is a system of dry cooling, but despite it can be used in areas where there are not available water resources, it is not as effective as cooling water in case temperature of the atmosphere is high. The power plant will not be as efficient as it could be and concerns for safety of the nuclear power plant would arise.

The temperature of water released has negative impacts. First of all, the amount of oxygen in water decreases and temperature of water of reservoir is

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[35] Tripathy A., Mishra A. K., Kumar Dubey A., Tripathy C. B. (2015), Water Pollution Through Energy Sector, *International Journal of Technology Enhancements and Emerging Engineering Research, Vol. 3*, p. 92-96. http://www.ijteee.org/final-print/mar2015/Water-Pollution-Through-Energy-Sector.pdf

[36] IEA, (2016), Water Energy Nexus – Excerpt from World Energy Outlook 2016 (online), p. 5. https://www.bt-projects.com/wp-content/uploads/documents-public/Environment/IEA-2017-Water-Energy-Nexus.pdf

[37] World Nuclear Association (2019), Cooling Power Plants. https://www.world-nuclear.org/information-library/current-and-future-generation/cooling-power-plants.aspx#.Udx22awzZqM

increased above heat pollution standards. In addition, aquatic ecosystems are affected. Many species may be endangered or extinct and biodiversity changes. As temperature of water in the reservoir is increased, then the efficiency of the power plant may be limited. There are also concerns for water-intake systems, as fish and crustaceans could be trapped and be killed due to impingement and entrainment. Furthermore, high temperature increases the growth of seaweed and algal and possibilities of blocking cooling water intake arise. Several technical solutions have been developed to limit these impacts, but they are expensive[38]. Furthermore, cooling towers consume greater amounts of water. New kind of cooling systems and reactors are designed and technology makes efforts to reduce negative impacts of nuclear energy in water security.

In addition, water remains in central position even when a nuclear power plant is shut down, as heat continues to be generated. Nuclear power plants are designed in such way that appropriate cooling systems continue to operate to decrease high temperatures.

Electricity production is also affected by the impacts of climate change in water cycle. Because of increased precipitation, greater amounts of water are available in reservoirs to be used as cooling water. In case rainfalls are decreased, the existence of a nuclear power plant can be threatened and alternative technological patterns (reuse of waste water, new types of cooling, extend of dry cooling etc.) have to be adopted. The rise of sea level can also affect the operation of a NPP. In combination with extreme weather events, they could lead to floods and measures should be taken in order to protect facilities of NPPs. In general, nuclear activities have to be prevented in flood prone areas, as many hard measures have to be adopted for the protection of NPPs.[39]

The role of water is determinant in NPPs. Although it is a low carbon technology and it has positive environmental impacts, it does not decrease water consumption according to future scenarios[40]. In addition, every change in reservoirs and the temperature of their water may lead to the destabilization of operation of the NPP. It decreases its efficiency, it risks its safety and it causes damages to the environment. Nuclear industry tries to adapt measures to solve and prevent such problems. However, environmental risks remain high and concerns about the use of nuclear energy continue to exist.

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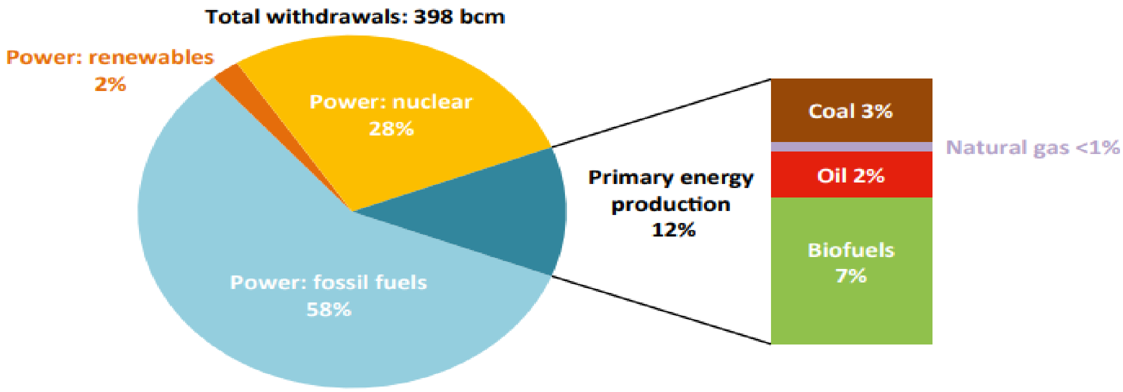
[38] Supra note 37

[39] IAEA (2018), Chapter 5.5: Adaptation of Nuclear Energy to Climate Change, *Climate Change and Nuclear Power 2018* (online), p. 100-108. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

[40] IEA (2016), Water Energy Nexus– Excerpt from World Energy Outlook 2016 (online), p. 12-22. https://www.bt-projects.com/wp-content/uploads/documents-public/Environment/IEA-2017-Water-Energy-Nexus.pdf

Figure 12: Water Withdrawals in the Energy Sector, 2014



Power generation is by far the largest source of energy-related water withdrawals

Notes: Renewables includes solar PV, CSP, wind, geothermal and bioenergy. Water requirements are quantified for "source-to-carrier" primary energy production (oil, gas, coal), a definition which includes extraction, processing and transport. Water withdrawals and consumption for biofuels account for the irrigation of dedicated feedstock and water use for processing. For electricity generation, freshwater requirements are for the operational phase, including cleaning, cooling and other process related needs; water used for the production of input fuels is excluded. Hydropower is excluded.

Source: IEA (2016), Water Energy Nexus. Retrieved from https://www.bt-projects.com/wp-content/uploads/documents-public/Environment/IEA-2017-Water-Energy-Nexus.pdf (p. 14)

3.3 The problem of Nuclear Waste

During energy production all industries produce waste. They have to be managed in a way that will not threaten human health and life. Their negative environmental impacts have to be decreased. This is one of the concerns of producing energy by nuclear power plants. Most of the nuclear waste produced is radioactive and it has to be managed carefully, as it has a high level of risk for human life and environment. Safety has to be the priority of nuclear industry and each country has to set necessary measures and policies.

Radioactive waste is both materials which include radioactivity and materials which are contaminated by radioactivity and it cannot be used any more. It is divided according to the level of radioactivity. There are low-level (LLW), intermediate-level (ILW), or high-level (HLW) waste.

Low-level waste is almost 90% of the total volume of waste but it includes only 1% of radioactivity of it. It has a very low level of radioactivity (4-12 GBq/t) and it can be disposed near surface facilities. It is not generated only by NPPs[41]. According to IAEA Publication of 2018 "*LLW includes contaminated clothing, protective shoe covers, floor sweepings, mops, filters and tools*"[42]. It does not produce heat, but it has to be isolated for many years until radioactivity reaches natural levels.

[41] World Nuclear Association (2018), Radioactive Waste Management. https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx

[42] IAEA (2018), Chapter 5.2: Spent Nuclear Fuel and Radioactive Waste, *Climate Change and Nuclear Power 2018* (online), p. 73. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

In addition, intermediate-level waste is more radioactive than LLW and it produces more heat. However, the heat is not adequate and it is not necessary to be taken into consideration during the design and the selection of disposal and selection facilities. However, shielding is necessary when it is stored or transported and it is disposed underground, in specifically designed facilities. World Nuclear Association claims that *"ILW typically comprises resins, chemical sludges, and metal fuel cladding, as well as contaminated materials from reactor decommissioning. Smaller items and any non-solids may be solidified in concrete or bitumen for disposal."*[43] It is 7% of the total volume of waste and it contains 4% of radioactivity[44].

Such disposal facilities of LLW and ILW are under construction or they operate in several countries of the world. Their existence depends on policies and practices of each state.

Finally, there is high-level waste which is only 3% of the volume of total waste, but it produces 95% of total radioactivity. It includes products and elements produced in nuclear reactor. Spent fuel is radioactive and has high temperature. Therefore, it has to be cooled and then shielded in engineered pools. This procedure differs from NPP to NPP, as the capacity of the pools needed is not the same to all facilities and there is need of constructing such facilities away from reactors, using other wet or dry technologies, depending on the technology available to each state. These technologies are mature because of their operational experience. This initial storage can last several years.

The most significant issue is nuclear waste management. Each state chooses if spent fuel will be disposed, as it is considered waste, or if it will be reprocessed, according to its regulation, its technology, its energy needs and taking into consideration public acceptance. In case it is reprocessed, new reactor fuel will be manufactured using plutonium and uranium which are main components of reprocessed material. Otherwise, these materials and waste will be considered as HLW and they will be disposed.

On the one hand, reprocessing is a procedure with positive impacts in energy security and environment. First of all, nuclear waste is solid waste and every day great amounts of it is created. It was claimed, for example, that *"By the year 2030 the United States' reactors will have produced about 96,000 tons (87,700 metric tons) of spent reactor fuel."*[45] HLW need many years in order to be disposed and deep geological formations have to be constructed. Several technical aspects and information have to be clarified to each state so as to allow the construction of disposal facilities, as strict safety measures have to be set in order to ensure public security[46]. These facilities have to be located in areas sparsely located. The area has to be quiet by a geological

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[43] Supra note 41

[44] World Nuclear Association, What are nuclear wastes and how are they managed? https://www.world-nuclear.org/nuclear-basics/what-are-nuclear-wastes.aspx

[45] Tabak J. (2009), Chapter 6: Spent Fuel, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 110

[46] IAEA, *Methodology for a Safety Case of a Dual Purpose Cask for Storage and Transport of Spent Fuel Report of WASSC/TRANSSC joint working group 2011-2013 (Draft)*. http://www-ns.iaea.org/downloads/rw/waste-safety/disp/dual-purpose-spent-fuel-cask-draft-tecdoc.pdf

aspect and it is preferable a little water to exist in order to prevent possible release of waste to the environment. However, despite how careful these facilities are constructed, it cannot be predicted how they will behave in the future[47]. As a result, the process of opening such disposal facilities is slow. A few states have started designing and constructing such facilities. Sweden, for example, applied for a construction license for such a facility in 2011[48]. Except from Sweden, Canada, Finland, Germany and the USA are some of the countries that prefer disposal of spent fuel. In contrary to permanent disposal, thanks to reprocessing a great amount of spent fuel is recycled and the total amount of waste, which will be disposed, is going to be reduced. China, France, India, Japan, Russia and the United Kingdom are some of the countries that reprocess and recycle their spent nuclear fuel.

The second advantage of reprocessing spent nuclear fuel is that nuclear reactor fuel is produced without mining. As a result, energy security is promoted. For example, Japan is a state with few natural resources and reprocessing could be beneficial. As it is mentioned in World Nuclear Association website " *This process allows some 25-30% more energy to be extracted from the original uranium ore, and significantly reduces the volume of HLW (by about 85%)*"[49]. France is also one of the countries that reprocess spent fuel and it also undertakes reprocessing for utilities in other countries[50].

On the other hand, despite the positive impacts of reprocessing, some countries have not such programs. For example, the USA were reprocessing spent fuel in 1960s, but these programs were terminated because of fear that terrorists could use the plutonium produced to construct nuclear weapons[51]. National security was their priority. Furthermore, a state may not be able to reprocess for financial reasons or because of lack of the necessary technology.

It is obvious that although reprocessing of nuclear spent fuel may be beneficial for the environment and it is mature because of operational experience, serious concerns still exist. There are efforts of developing new type of reactors which will be able to reduce the amount of waste generated[52].

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[47] Tabak J. (2009), Chapter 6: Spent Fuel, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 115-122

[48] IAEA (2016), Chapter 4.7: Waste Management and Disposal, *Climate Change and Nuclear Power 2016* (online), p. 69-72. https://www-pub.iaea.org/MTCD/Publications/PDF/CCANP16web-86692468.pdf

[49] Supra note 41

[50] Supra note 41

[51] Tabak J. (2009), Chapter 6: Spent Fuel, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 109-115

[52] IAEA (2018), Chapter 5.2: Spent Nuclear Fuel and Radioactive Waste, *Climate Change and Nuclear Power 2018* (online), p. 76-80. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

Chapter 4: Concerns and safety issues of Nuclear Energy

4.1 Nuclear Accidents

Nuclear accidents is one of the most significant concerns of nuclear energy. Accidents may take place in different stages of the energy production. Their impacts may be hazardous for human health and environment and they have a determining role in the acceptance of nuclear energy in the energy mix, as public opinion is dramatically affected by their consequences.

First of all, technological problems or damages can cause fatal accidents. The operation of nuclear reactors is a central issue of safety record. Historically, the number of accidents is not important, if we take into consideration the years of experience and operation of nuclear power plants. In order to examine the level of importance of an accident and how we can prevent it, we have to appreciate engineering principles, mathematics, medicine, and other fields as well. Human factor and the possibilities of an accident because of a human error during the operation of the reactor cannot be excluded, as they are main reasons of nuclear accidents. Despite the adoption of safety measures to reduce the risk of an error, chances for such a risk remain. Finally, there are not only internal reasons for these accidents, but external reasons, too. Natural disasters and other unpredictable external events can disturb the operation of an NPP in a catastrophic way. The three most well-known and disastrous accidents were results of these factors.

Nuclear accidents are divided to levels in order to clarify the importance of the accidents and their radiological events to the public. This is the reason why a special tool, the International Nuclear and Radiological Event Scale (INES), was created. Accidents are separated according to the radioactive material released and the number of people exposed to it[53]. The nuclear accidents of Chernobyl and Fukushima Daiichi are the only accidents of level 7.

The impacts of a nuclear accident affect public health and the environment. Because of the accident, an amount of radiation is released. The consequences of radiation to human health depend on the amount, the type of radiation which is absorbed by human body and the degree of exposure. Every day we are exposed to minus amounts of radiation which are not emitted by nuclear power plants[54]. In case of an accident the exposure in high levels of radiation causes or increases health risks. The percentages of leukaemia, cancer of thyroid and other health problems were increased to population living near the areas of blast, as it was proved after long-term studies of survivors of atomic bombing of Hiroshima and Nagasaki in 1945 and after

[53] IAEA - INES. https://www.iaea.org/resources/databases/international-nuclear-and-radiological-event-scalehttps://www.iaea.org/resources/databases/international-nuclear-and-radiological-event-scale

[54] United Nations Scientific Committee on the Effects of Atomic Radiation (2017). https://www.unscear.org/unscear/en/faq.html

the Chernobyl accident in 1986[55]. It was proved that there is a strong correlation of leukaemia and exposure to radiation. For ten years after the exposure, many cases of leukaemia were developed. Several other types of cancers respond to the radiation exposure afterwards and some of them were fatal. As a result, the consequences can delay for many decades after the nuclear accident[56]. Negative impacts of radiation also affect the environment. It is claimed that population of animals may be decreased, growing plants can delay and water resources can be contaminated by radioactivity. Ground can also be contaminated by radionuclides emitted and harm crops production.

There are two categories of NPP accidents. The first category is a loss-of-coolant accident. When the cooling system of the NPP does not manage to remove the thermal energy from nuclear reactor, the temperature of the fuel increases and a series of negative impacts in the reactor may damage it. The second type of accident is caused when the output from the reactor is increased in an uncontrolled way and serious concerns on safety issues arise (criticality accident). Several safety systems have been developed thanks to technology in order to decrease the possibilities of such accidents and prevent them. Reactors are equipped with several independent safety systems, as it is unlike multiple systems to fail simultaneously[57].

The improvement of reactors' technology is based on operational experience, development of technology and the observation of previous failures which led to accidents. The World Association of Nuclear Operators (WANO) was created after the Chernobyl accident in order to spread several safety practices, promote safety and share experience and expertise among states with NPPs[58]. Safety is one of the pillars of operation of an NPP, not only because of the negative effects of an accident in human health and environment, but because of its financial impacts. Great financial penalties have to be paid in case of violation of safety measures which cause a nuclear accident. These accidents help states to realise the importance of nuclear safety. For example, the EU published a proposal for amendment of EU direction after the nuclear accident of Fukushima Daiichi[59].

Several accidents have been caused since nuclear power plants started operating. However, because of the technology development and the operational experience, not all of them had serious damages[60]. Based on these facts, many people claim that nuclear energy is one of the safest ways to produce electricity. There are

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[55] Tabak J. (2009), Chapter 5: Reactor Safety, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 90-95

[56] Bodancky D. (2004). Chapter 4: Effects of Radiation Exposures, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 85-121

[57] Tabak J. (2009), Chapter 5: Reactor Safety, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 95-101

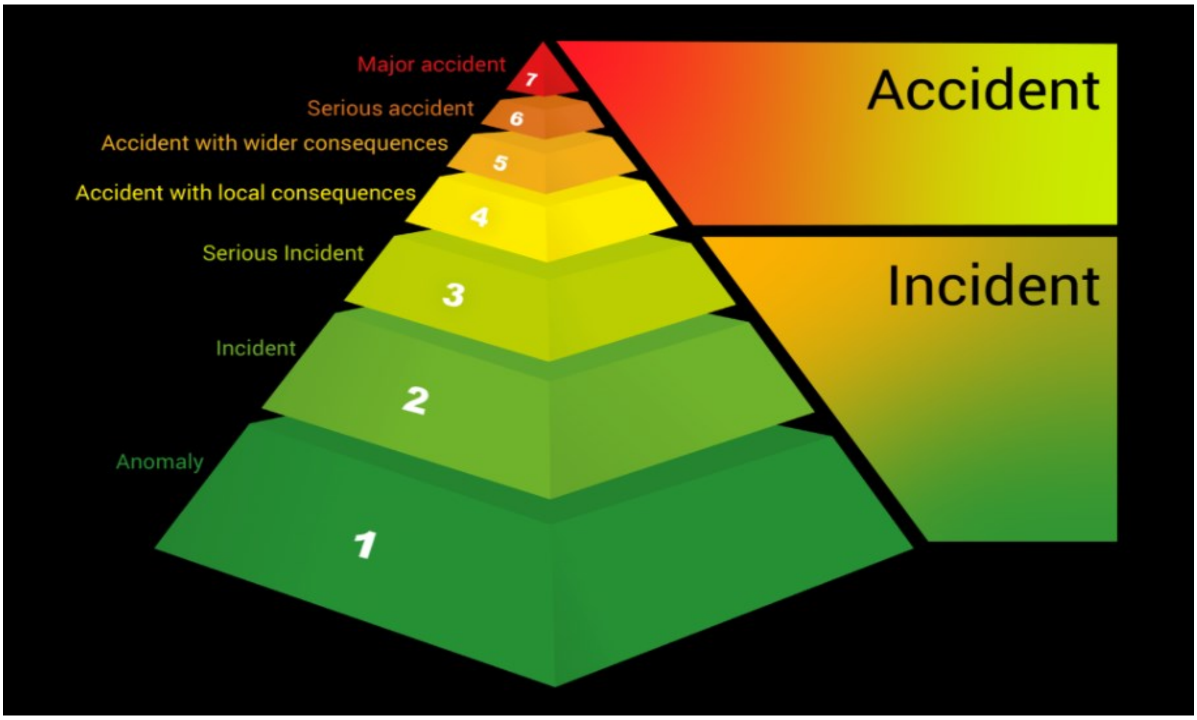
[58] IAEA (2018), Chapter 5.3: Off-Site Effects, *Climate Change and Nuclear Power 2018* (online), p. 80-86. https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf

[59] European Commission (2013), Proposal for the Amendment of EU Direction 2009/71/EURATOM. https://eur-lex.europa.eu/legal-content/EL/TXT/PDF/?uri=CELEX:52013PC0715&from=EN

[60] The Guardian, Nuclear power plant accidents: listed and ranked since 1952. https://www.theguardian.com/news/datablog/2011/mar/14/nuclear-power-plant-accidents-list-rank

not many significant accidents, in order to study their effects in a systematic way. However, the three most important accidents had such catastrophic impacts that create serious concerns on producing electricity to NPPs. Public opinion is affected by their results, as people are terrified and they are against spreading nuclear energy use. The accidents defining the development of nuclear industry and relative regulations are the Three Mile Island accident in 1979, Chernobyl in 1986 and Fukushima Daiichi in 2011.

Figure 13:



Source: IAEA - INES. Retrieved from https://www.iaea.org/resources/databases/international-nuclear-and-radiological-event-scale

- Three Mile Island Accident (1979):

This accident was caused by a technical failure of the cooling system. Despite the fact that nuclear reactors are designed to handle such failures, human error of operators, their lack of correct information or their insufficient training led to a series of wrong actions. As a result, the seriousness of the problem was recognized after the accident has started.

For a few days the situation was not able to be controlled. The release of an unspecified amount of radioactivity led to the belief that the amount released was significant and the evacuation of pregnant women and children was considered as the most appropriate solution. Even when it was realized that the amount of radiation released was not important, the evacuation was not immediately withdrawn by government.

There were concerns that the number of cancers would increase in areas near the NPP. According to studies only cancer incidents were increased at areas near the NPP from 1982 to 1985, not cancer fatalities[61]. These results could be affected by other causes (e.g. stress caused by the accident). There were also cancer incidents independent of the accident. It is commonly accepted that despite the serious damage of the reactor, the release was negligible and it did not affect individuals and the environment seriously.

This accident was the reason for several changes to take place in nuclear industry related to safety measures, licensees and public health. The equipment of facilities should be upgraded. The need of training the staff was imperative, as human have a decisive role during the operation of NPP. Furthermore, measures for the preparedness of the NPP in case of a failure were designed and they are tested several times a year. Experience and expertise should be shared among states where NPPs operate in order to develop their facilities[62].

To sum up, this accident did not cause serious negative impacts to public health and environment and it benefited safety measures of nuclear industry, but the fear caused and the probabilities of a similar situation in the future created serious concerns for the operation of NPPs.

- Chernobyl (1986):

It is the most disastrous nuclear accident and it strengthens the position of those who are against nuclear energy. The exact reasons of the accident are not clear, however it is claimed that it is a result of operational failure, the design of the reactor and the lack of the necessary safety culture not only at Chernobyl NPP, but at Soviet Union facilities, operating and design organizations in general. The design of Chernobyl reactors is unique. Western states did not use such reactors and they do not tent to. This is the main argument in favour of nuclear energy, as such an accident has not been noted to western designs of nuclear reactors[63].

The accident was caused while safety features of the reactors were tested[64]. Because of the accident, radioactive materials were released from the reactors for many days after the initial explosions and fires. The cloud of radioactivity was expanded because of the wind to several directions and the distance from the nuclear reactor was not a determining factor for the concentration of radiation in a specific area, as wind and rainfalls affected it. However, the accident and the release of radioactivity was not published because of the politics of the Soviet Union. In Sweden,

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[61] Bodancky D. (2004). Chapter 5: Nuclear Reactor Accidents, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 414-420

[62] U.S.NRC (2018), Backgrounder on the Three Mile Island Accident. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html

[63] Bodancky D. (2004). Chapter 5: Nuclear Reactor Accidents, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 421-423

[64] Bodancky D. (2004). Chapter 5: Nuclear Reactor Accidents, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 423-425

for example, the cloud was detected two days after the accident. Radiation was detected to several states of the whole North Hemisphere.

Impacts of the accident were devastating. First of all, several deaths and injuries were caused because of radiation within a few weeks. Except from people who died because of immediate exposure to radiation after the accident (workers, firemen, liquidators), several incidents of thyroid cancer were noted, especially to children. Doses of radioactivity were received even weeks after the accident through the consumption of local products or inhalation. According to the UNSCEAR, it is claimed that public health impacts because of radiation exposure are not as major as it was expected[65]. However, many people do not support these conclusions, as they believe that defenders of atomic energy do not agree about the level of these negative consequences in order to serve other financial and political interests[66]. In addition, Greenpeace predicted a greater number of deaths because of radiation. The difference of the number of deaths was the result of different models of studies[67]. Except from injuries and deaths, social and psychological disruption were caused. Stress and anxiety were results of the accident and the evacuation was risen. In coordination with financial impacts, as there was need of remedial measures and the economic condition of the Soviet Union was already poor, fear of people was increased.

Areas surrounding the nuclear reactor were evacuated by authorities. Almost 115.000 people had to evacuate their homes to a 30-km exclusion zone and it remains largely uninhabited till today. This was the result of large exposure of people to radiation through inhalation during the passage of radioactive cloud. After its passage, radionuclides deposited on the ground emitted radioactive materials. Because of rain, the exposure of the ground was increased. As a result, growing crops was inhibited to contaminated areas, having negative impacts to economy. In addition, a forest near the NPP was named "Red Forest" as leaves of trees became red because of radiation. The population of many animal species was decreased. Most of studies claim that some years after the accident population and wildlife of the contaminated area were recovered. However, according to other studies, animal populations are not as abundant as in other areas where radiation levels are not very high and growth of flora is delayed. More studies with specialized scientists are necessary in order to decide how to manage exclusion zone[68].

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[65] United Nations Scientific Committee on the Effects of Atomic Radiation (2012), The Chernobyl accident. https://www.unscear.org/unscear/en/chernobyl.html

[66] Yablokov V. A. et al. (2009), *Chernobyl: Consequences of the Catastrophe for People and the Environment, Annals of the New York Academy of Sciences, Vol. 1181* (online).
https://books.google.gr/books?hl=el&lr=&id=g34tNlYOB3AC&oi=fnd&pg=PR7&dq=environmental+impacts+of+nuclear+accidents&ots=O3b0bT0_f8&sig=sLWllorqSgE1jTiUByUtnJK5sc4&redir_esc=y#v=onepage&q=environmental%20impacts%20of%20nuclear%20accidents&f=false

[67] Tabak J. (2009), Chapter 5: Reactor Safety, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 96-98

[68] Barras C. (2016), The Chernobyl Exclusion Zone is arguably a nature reserve, BBC.
http://www.bbc.com/earth/story/20160421-the-chernobyl-exclusion-zone-is-arguably-a-nature-reserve

Chernobyl accident also had a significant role in collapse of Soviet Union, as its clumsy reaction strengthened the lack of trust of other states. Internal issues arose as negative impacts of the accident were greatest in Ukraine and Belarus, which were Soviet Republics. Finally, this accident came when serious concerns for nuclear energy had already existed because of Three Mile Island accident seven years ago. As a result, it effected the progress of nuclear industry[69].

- Fukushima Daiichi Accident (2011):

In this case, a nuclear accident was caused because of unpredictable natural disasters. An earthquake of magnitude 9.0 created considerable damages and a large tsunami which had devastating consequences. When earthquake hit, nuclear reactors shut down automatically. However, they were vulnerable to the tsunami. Although in the beginning the accident declared as level 5, its finally rating was raised to 7, as it was claimed that the release of radiation was greater than it was first estimated. Despite of the fact that the level of accident is the same with Chernobyl accident, its environmental impacts are not as great as those of Chernobyl because authorities and organizations reacted immediately. It is foreseen that its health impacts are significant lower[70].

Because of the tsunami, the reactor cooling and water circulation functions stopped maintaining properly. Efforts to cope with spent fuels and restore damages were extremely difficult. Most of the employees had to deal with their personal tragedies caused by natural disasters. It was very difficult to take decisions immediately after the tsunami, as workers were under extraordinary stress. There was the fear of preventing fuel damage. The authorities decided the evacuation of a zone of 20-30 km. Radionuclides were released to the air and water. As it is mentioned in the website of World Nuclear Association "*Regarding releases to air and also water leakage from Fukushima Daiichi, the main radionuclide from among the many kinds of fission products in the fuel was volatile iodine-131, which has a half-life of 8 days. The other main radionuclide is caesium-137, which has a 30-year half-life, is easily carried in a plume, and when it lands it may contaminate land for some time. It is a strong gamma-emitter in its decay. Cs-134 is also produced and dispersed, it has a two-year half-life. Caesium is soluble and can be taken into the body, but does not concentrate in any particular organs, and has a biological half-life of about 70 days*"[71]. It is obvious that the danger of contamination from radiation exists for many years after the accident. However, necessary measures for decontamination have been taken.

It is difficult to calculate the number of deaths caused by radiation. First of all, it is claimed that the level of radiation did not exceed the ordinary ones. Furthermore,

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[69] Bodancky D. (2004). Chapter 5: Nuclear Reactor Accidents, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 434-436

[70] Steinhauser G. et al. (2014), Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts, *Science of the Total Environment, Vol. 470-471*, p. 800-817. https://www.sciencedirect.com/science/article/pii/S004896971301173X

[71] World Nuclear Association (2018), Fukushima Daiichi Accident. https://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/fukushima-accident.aspx

the earthquake, the tsunami and the stress of evacuation have cause numerous deaths and health damages. In addition, there are people who do not intent to return to their homes, because of fear of possible exposure to radiation. There are also concerns as contaminated water at Fukushima has to be removed and treated. An amount of contaminated water was released to the Pacific Ocean and although it is claimed that it has low-level radiation, it remains one of the most serious threads for the environment and public health. When environment is contaminated, a great amount of resources, time and specialized technologies are required. Proposals and strategies for the treatment and management of contaminated water were devised by national institutes, TEPCO and the JAEA in order to eliminate contamination. Local communities and especially fishing industry are against strategies of discharging groundwater to the ocean, as they are afraid of wider contamination[72].

The accident was not the result of natural disasters only, but it could be preventable if TEPCO and NISA had took into consideration all the necessary practices, standards and safety measures. During construction of facilities, the attention given for the possibilities of large tsunamis at the area were insufficient, as they were focused on examining safety measures in case of earthquakes. Simulations made by TEPCO, in order to determine how far above sea level a tsunami would reach, were inadequate. As a result, safety systems of NPPs in Japan were not as protected as in other states. NISA had failed to comply its responsibilities with tsunami safety standards and to update them according to new evidence and international standards. Also, Japan is a country with high level of dependence on nuclear energy. According to its regulation, NPPs continue to operate after thirty years of operations without examining safety issues but focusing on plant aging. One of the units of Fukushima Daiichi had extended its operating license after a technical review a month prior the accident. After the accident, stringent requirements and procedures has been approved for license extension and safety measures. Except from safety measures, another reason which had negative impacts to nuclear industry of Japan was the lack of independence of NISA from government and nuclear industry[73].

Based on researches which were carried out after the accident, it was proved that extreme external events were not exclusively responsible for the accident. Examining international safety standards and those of Japan, it was noted that Japan was not extremely careful to their adoption, because of its politics, its national safety standards and its goals. The accident was preventable, however this claim cannot be certain, as human factor, possible technological problems, other external factors and their consequences cannot be prevented. Nonetheless, this accident was the catalyst for changes in safety standards and measures of nuclear industry of other countries.

[72] Marui A. et al. (2015), Managing Groundwater Radioactive Contamination at the Daiichi Nuclear Plant, International Journal of Environmental Research and Public Health,12, p. 8498-8503. https://pdfs.semanticscholar.org/ff24/fbd64e2b1e89e49273f64d4e122f5764f278.pdf

[73] Acton M. J. et al (2012). Why Fukushima Was Preventable, Carnegie Endowment for International Peace. https://carnegieendowment.org/2012/03/06/why-fukushima-was-preventable/a0i7

4.2 Nuclear Weapons

4.2.1 History of Nuclear Weapons

During World War II scientists who had moved from Europe to the United States managed to develop and use nuclear bombs based on nuclear fission. The first and unique use of the nuclear bombs in combat was in 1945, when the United Stated dropped bombs at Hiroshima and Nagasaki in Japan. There are contradictory opinions for the reason of using these bombs. On the one hand, it is claimed that it was a way to finish war between the USA and Japan. On the other hand, there are historians who claim that there are also other reasons which led Truman to this decision. It was an indirect way to make the Soviet Union follow the post-war interests of the USA. The number of victims was extremely important, as almost 80.000 people died in Hiroshima and 40.000 in Nagasaki immediately after the explosion of the bomb. The number increased the following days and years because of the radiation released from the explosion[74]. The atomic bomb changed the nature of the world warfare.

After the end of War, the development of nuclear weapons and the spread of their use to several countries was a result of Cold War. Both the United States and Soviet Union, in order to ensure and protect their national security, developed their nuclear programs. Western countries were afraid that the policy of Soviet Union had an ideological basement and the United States wanted to protect Western Europe by locating nuclear weapons to the territory of states of Western Europe and using them in case of an attack, as it was provided in NATO. It is worth noting that by 1960s there were almost 7.000 nuclear weapons in Western Europe. The coexistence of these two superpowers was difficult. Both of them were trying to prevent the other superpower from acquiring nuclear supremacy. The fear of a nuclear war and its unpredictable consequences were some of the main reasons why it was prevented. However, there were some events during Cold War that brought these superpowers close to nuclear war. Cuban Missile Crisis in 1962 was the most critical moment, but the reason why such a war was prevented is still a controversial issue.

After this crisis, the USA and Soviet Union tried to reduce nuclear tension and manage their relations with diplomacy and cooperation. Nonetheless, the internal political issues, the political figures of each state and their external policies affected them and tension was risen again. The fact that the Soviet Union was supporting revolutions to Third World countries increased the tension again. The situation started changing when Gorbachev became the General Secretary of the Soviet Union. His reforms to domestic policy issues were successful in order to restructure society and economy of the USSR. He did not intend to use violence as far as it concerned issues of foreign policies. The Cold War was led to an end and the Soviet Union collapsed in 1991. In order to increase the trust of Western Europe, treaties for nuclear weapons

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[74] Baylis J. et al. (2007), Κεφάλαιο 4: Διεθνής Ιστορία, 1945-1990, *Η Παγκοσμιοποίηση της Διεθνούς Πολιτικής. Μια εισαγωγή στις διεθνείς σχέσεις*, Εκδόσεις Επίκεντρο, p.147-168

were made. However, after the end of Cold War, states managed to control the proliferation of nuclear weapons but not to promote nuclear disarmament.

The first effort to prevent the spread of nuclear weapons was the establishment of an autonomous organization, the International Atomic Energy Agency (IAEA) in 1957[75]. Its main purpose was the promotion of peaceful nuclear uses (e.g. agriculture, medicine) and it established safeguards to prevent the development of nuclear weapons. To deal with the problem of nuclear weapons proliferation, the Non-Proliferation Treaty (NPT) was adopted and it went into force in 1970[76]. The development of peaceful nuclear uses and the discouragement of military uses, the nuclear disarmament and the end of practice of testing explosions of nuclear weapons are the main motivations of this Treaty. Nuclear weapon states (NWS) were USA, Russia, China, France, and the United Kingdom. These states and the states that became parties to the Treaty do not have to develop nuclear weapons in a non-NWS and the non-NWS do not have to construct or to receive nuclear weapons. However, there are states which do not have nuclear weapons, but they have all the necessary know-how to construct and to transfer them. Nuclear stability was also achieved thanks to this Treaty, at its importance was realized when USSR collapsed and there was the risk of creation of more NWS (Russia, Kazakhstan, Ukraine, Belarus).

4.2.2 The spread of Nuclear Weapons

The dilemma if the development of nuclear weapons has positive or negative effects in the strategic position of a state and its national security still exists. This is the reason why the number of states having nuclear weapons has increased and nuclear disarmament has not been achieved. The concerns for their spread are a result of their potential catastrophic consequences, as they were noted after the explosion of nuclear bombs to Hiroshima and Nagasaki and after the release of radiation at the nuclear accident of Chernobyl in 1986. They are weapons of mass destruction (WMD)[77]. However, there is also the assertion that nuclear weapons ensure peace. Cold War is an example of this claim, as nuclear war was prevented because of fear of both USA and USSR in case of using nuclear weapons.

On the one hand, according to Kenneth N. Waltz[78], the spread of nuclear weapons is determining for the conservation of national security and peace. States coexist in an anarchic world, where they fight to protect their own security without using force. If nuclear weapons make the deterrence and defence of a state easier, then states may decide to protect their security using the fear these weapons cause.

In order to develop such nuclear programs, states need a long time period. This is the reason why domestic stability of the state is necessary. It is claimed that the

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[75] Tabak J. (2009), Chapter 3: Reactor Fuel- The International Atomic Energy Agency, *Nuclear Energy*, Facts On File, Inc, New York, USA, p. 58-60

[76] UN Office for Disarmament Affairs, Treaty on the Non-Proliferation of Nuclear Weapons (NPT). https://www.un.org/disarmament/wmd/nuclear/npt/

[77] NATO (2017), Weapons of mass destruction. https://www.nato.int/cps/en/natohq/topics_50325.htm

[78] Sagan D. S. et al. (2003), Chapter 1: More may be better, *The Spread of Nuclear Weapons*, W. W. Norton and Company, USA, p. 3-45

possession of nuclear weapons by a country prevents neighbouring countries from attacking and makes them more cautious. So, they maintain their peaceful coexistence, as they are not willing to pay a high price for minor gains. If the construction or the acquisition of nuclear weapons is not financially feasible, they search for support to powerful nuclear weapon states. The fear of retaliation is great. In case the defecting nuclear state uses its weapons to protect its territory, consequences will be disastrous for the attacker. Nobody can predict that the state attacked will be rational and it will not retaliate in the case of a nuclear attack. As a result, nuclear weapons change the dynamics of military powers. In addition, the result of a war cannot be foreseen, as many parameters (e.g. technological innovation, external factors) affect its outcome. It is significant that nuclear state has to appear to be able to attack and cause catastrophic damages to another state. Its threads have to be physically and psychologically feasible.

The new nuclear states will differ from the old ones, as there are worries for their reactions and the way they will deal with the power they acquire. Although it is believed that they will use them irresponsibly, Waltz claims that these weapons will be used only if their survival is threatened. This is also affected by the economy of new nuclear states, as some of them are economically hard-pressed and they want to possess only the necessary weapons for their survival. As a result, the gradual spread of nuclear weapons can be beneficial and it decreases the possibilities of a nuclear war to start. If the new nuclear weapon state is minor, then there is the danger of being struck by other nuclear powers so as to prevent the construction of such weapons. Such a preventive strike took place in 1981, when Israel struck to nuclear facilities of Iraq. However, such an attack can have the opposite consequences and it is unlikely. Furthermore, these states have to be careful with storage and preservation of weapons, as there is need of economic and technological backward and safety measures to prevent possible accidental crisis.

On the other hand, in contrast to the "proliferation optimist", there is a pessimistic vision of proliferation, according to Scott D. Sagan[79]. Stability and peace cannot be achieved because of nuclear proliferation, as military power is increased in nuclear weapon states and it affects policymaking. Military officers and organizations are predisposed to have a war. Because of their ideology and their position, they do not trust political solutions, they are focused on military logic that victory exists when the enemy is defeated. As a result, the possibilities of a war to start are risen, because a state can react irrationally. A preventive war may be more possible at a new nuclear weapon state, as the relations of civilians and military officers may be unstable and military power can take precedence over the political power. In addition, the possession of nuclear weapons helps states to gain military power to its region, as states without nuclear weapons will be vulnerable and unprotected against them. This power will define its decision making policy.

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[79] Sagan D. S. et al. (2003), Chapter 2: More will be worse , *The Spread of Nuclear Weapons*, W. W. Norton and Company, USA, p. 46-87

Because of nuclear proliferation, nuclear weapon states have also to deal with other negative impacts of nuclear weapons. The production of such military equipment and their safety design by experts is costly. Their safety issues are also affected by the lack of transparency to the proliferation process. An accidental nuclear war would be possible, in case a state develops weapons to cause fear or if internal or external political instability arose. The development of nuclear weapons also makes the new nuclear states a future target for preventive attacks. It is unlike an old nuclear state to cooperate with a new one, although such an action would be useful for safety practices, as these are sensitive issues and states do not want to be exposed.

However, there are states that desire to cooperate in a global level ridding the world of nuclear weapons, in order to be protected from risks of nuclear armament. There are treaties for the establishment of Nuclear Weapons Free Zone (NWFZ) and their purpose is to limit and prohibit nuclear weapons in specific locations. Gradually they hope that a nuclear free world will be achieved. Such treaties already exist and they cover even uninhabitable areas of the world (Antarctica, Latin America, Africa, Central Asia, Outer space, Seabed, Moon). Europe, North America, South and East Asia and Middle East are still not covered by such treaties, as nuclear weapon states exist in their territories. States of NWFZs and states developing and possessing nuclear weapons usually sign protocols defining that nuclear weapon states will not store, test or use nuclear weapons at the territories of NWFZs. Some of these treaties were signed after military and political crisis or they were the result of serious concerns of states because atmospheric, underwater, and above-ground nuclear testing was conducted to areas near their territories. Other reasons for establishing such a treaty was the existence of military bases of nuclear states at the territory of states proposing the creation of nuclear weapon free zones[80].

One of the main reasons of the creation of NWFZ is nuclear weapons testing. The purpose of these tests is testing nuclear weapons, examining military power and promoting the nuclear power of a state. Serious concerns are raised because of their effects in environment and national security. They cause atmospheric and oceanic environmental contamination. The exposure to radioactive pollution can cause health problems, as they release considerable amounts of radioactive materials. From the end of World War II since 2006, most nuclear tests were conducted by the USA and the USSR (85%), as they were nuclear superpowers, 14.5 % of them by United Kingdom, China and France and almost 1% by India, Pakistan and North Korea. Such tests were taking place underground, to the atmosphere or underwater. North hemisphere is more contaminated by radioactivity released during nuclear tests, as only France and United Kingdom used to conduct them to south hemisphere. It is

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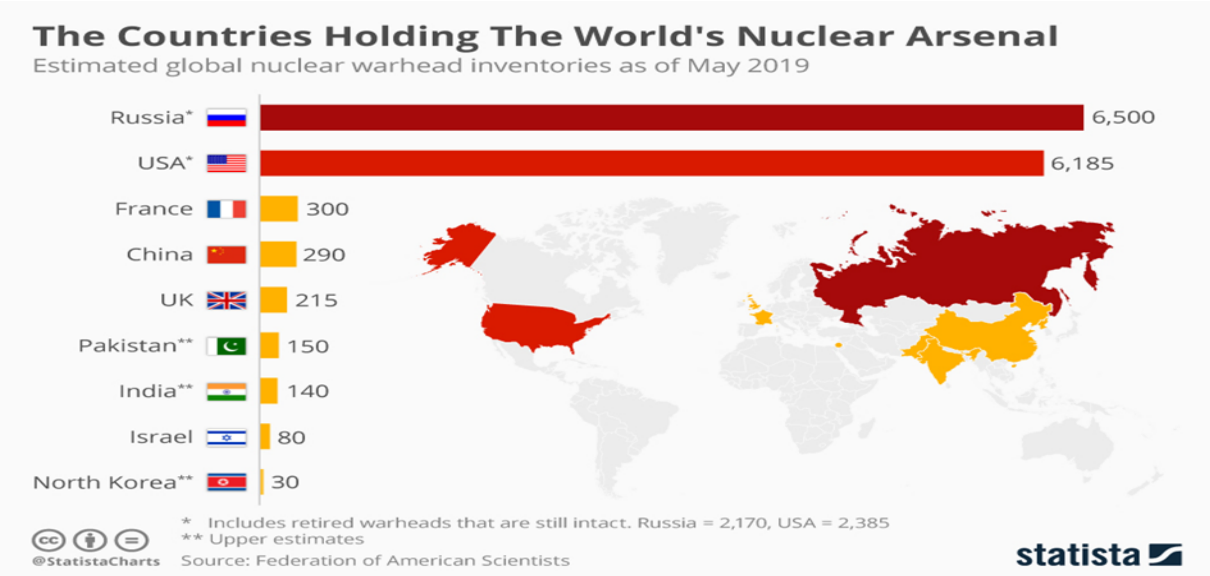
[80] Kutchesfahani Z. S. (2019), Chapter 3 - Regional Initiatives Toward a Nuclear Weapons Free World: The Case of Nuclear Weapons Free Zones, *Nuclear Safeguards, Security, and Nonproliferation: Achieving Security with Technology and Policy, 2nd Edition* (online), *p. 59-76*. https://www.sciencedirect.com/science/article/pii/B9780128032718000035

claimed that percentages of thyroid cancer occurrence are increased in the USA because of atmospheric nuclear tests conducted at Nevada desert[81].

By an international security aspect, further measures had to be adopted to promote nuclear disarmament and control nuclear proliferation. This is the reason why treaties for the prohibition and limitation of nuclear tests under water, in the atmosphere, or in outer space were signed. Such treaties are the Partial Test Ban Treaty (PTBT)[82] and the Comprehensive Nuclear-Test-Ban Treaty (CTBT)[83], which are signed but they have not yet entered into force. The latest nuclear test took place by North Korea in 2017[84].

4.2.3 Countries having nuclear weapons

Figure 14:



Source: Statista (2019). Retrieved from https://www.statista.com/chart/8301/the-countries-holding-the-worlds-nuclear-arsenal/

Nowadays, only 9 states possess nuclear weapons. Except from the NWS (USA, Russia, United Kingdom, China, France), there are also India, Pakistan, Israel and North Korea. It is estimated that these states possess almost 13.890 nuclear warheads[85].

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[81] Pravalie R. (2014), Nuclear Weapons Tests and Environmental Consequences: A Global Perspective, Ambio, Vol. 43 (6), p. 729-744. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4165831/

[82] UNODA, Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water. http://disarmament.un.org/treaties/t/test_ban/text

[83] UNODA, Comprehensive Nuclear-Test-Ban Treaty. http://disarmament.un.org/treaties/t/ctbt/text

[84] UNODA (2019), Fact Sheet: Comprehensive Nuclear-Test-Ban Treaty. https://s3.amazonaws.com/unoda-web/wp-content/uploads/2019/07/CTBT-Fact-Sheet-July2019.pdf

[85] Statista (2019). https://www.statista.com/chart/8301/the-countries-holding-the-worlds-nuclear-arsenal/

- Nuclear Weapon States

First of all, the United States was the first state that developed nuclear weapons during World War II according to the Manhattan Project. It also tested for the first time a nuclear bomb and it is the only country that had used them in war, dropping them at Hiroshima and Nagasaki in 1945. Russia took the same path a few years later. During the Cold War, the number of their weapons was increased and it was realized how sensitive the states are to each other's nuclear moves. The importance of nuclear weapons in strategic, military and political issues was proved and since then they define international relations. USA had all the necessary financial, technological and scientific background in order to develop them and increase the security measures for their construction, storage and transport. These states have the greatest percentages of nuclear weapons globally. Russia is at the top of the list having 6.500 nuclear warheads and the USA follows with 6.185 warheads. The United States have also thousands warheads awaiting dismantlement and other nuclear weapons located in other NATO countries[86].

United Kingdom was cooperating with USA and Canada at the Manhattan Project and it developed its own method for manufacturing a bomb after the end of World War II. However, it is planning to reduce more the number of its nuclear weapons[87].

France is the third state at the list and has signed the Nuclear Non-Proliferation Treaty, although it decreased its nuclear forces after the end of the Cold War.[88] Numerous anti-nuclear test protests have taken place because of the nuclear tests of France to Sahara and to French Polynesia since the end of 1950s.

The number of nuclear weapons of China is a state secret, but it is estimated that it possesses 290 nuclear warheads. They have declared that they will use their nuclear weapons only as a deterrence of an attack and that they will adopt a no-first-use policy as opposed to the United States. It has also improved its export controls of nuclear technology[89].

- States with nuclear weapon programs

India is not a member of NPT. In 1974 a peaceful nuclear test was made, rising the concerns of creating nuclear weapons secretly based on civilian nuclear technology. Anger was created to states which did not want to use their nuclear technology for military reasons. It was claimed that it desired to produce weapons because of the political condition with Pakistan. International community was fearing for possible escalation of conflict between the two states. However, despite the fact that India was claiming that it had no-first-use police, intervention of the USA and their cooperation changed the situation. Now India can participate in international nuclear

[86] NTI (2019), United States. https://www.nti.org/learn/countries/united-states/
[87] NTI (2016), United Kingdom. https://www.nti.org/learn/countries/united-kingdom/
[88] NTI (2016), France. https://www.nti.org/learn/countries/france/
[89] NTI (2019), China. https://www.nti.org/learn/countries/china/

trade and its nuclear facilities are divided to the military and the civilian ones. It has a strong presence to nuclear industry[90].

In addition, Pakistan developed its nuclear weapons because of its defeat in the Indo-Pakistani War of 1971. Its first nuclear test took place in 1998 and it declared itself a nuclear weapon state without becoming a party of NPT[91].

- States Believed or be controlled to have nuclear weapons

Israel, like India and Pakistan, is not a party of NPT. It is generally agreed that it possesses nuclear weapons, but Israel has never confirmed or denied it. It also claims that it will not be the first state in Middle East which develops nuclear weapons[92].

North Korea is the only state that withdrew from the NPT in 2003. It is a great example of how a small country with limited technical base managed to develop nuclear weapons. However, its present political status raises serious concerns in international relations. Despite the prohibition of nuclear tests, it is the only country that has carried out nuclear tests the last decades[93].

Iran is another state that creates serious concerns about its nuclear program. It has developed a nuclear program for the electricity production, but there are serious concerns globally that it is a covert way to produce nuclear weapons. In 2015, it has signed JCPOA, in which inspections are provided to Iranian nuclear power plants and its technology in order to limit the possibility of producing weapons[94]. Contradictory opinions exist for the benefits of the production of a nuclear bomb[95]. Despite several sources which claim that Iran is almost ready or that it has already produce a nuclear bomb, no credible evidence of nuclear weapon activity exist[96].

4.3 Terrorism and Nuclear Energy

Since the terrorist attack in New York in 2001, many concerns for other possible terrorist attacks have risen to the USA and several other Western countries. Energy infrastructures and energy supply chains are attractive targets which may have significant economic impacts and damages. Energy prices may be increased or decreased affecting local and international economy and the disruption of energy chain can affect individuals' lives to all over the world.

One of the most critical energy infrastructure is power plants of the nuclear sector. An important amount of electricity is produced by nuclear power plants.

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[90] NTI (2019), India. https://www.nti.org/learn/countries/india/nuclear/
[91] NTI (2017), Pakistan. https://www.nti.org/learn/countries/pakistan/
[92] NTI (2017), Israel. https://www.nti.org/learn/countries/israel/
[93] CNN (2019), North Korea Nuclear Timeline Fast Facts. https://edition.cnn.com/2013/10/29/world/asia/north-korea-nuclear-timeline---fast-facts/index.html
[94] Arms Control Association, Section 3: Understanding the JCPOA. https://www.armscontrol.org/2015-08/section-3-understanding-jcpoa
[95] Kenneth N. Waltz N. K. (2012), Why Iran should get the bomb: Nuclear Balancing Would Mean Stability, *Foreign Affairs, Vol. 91*, p. 2-5
[96] NTI (2019), Iran. https://www.nti.org/learn/countries/iran/

Countries, such as France, cover their energy needs by domestic production of electricity by NPPs. However, despite their importance, nuclear facilities are not such significant targets for terrorists[97]. Most of NPPs are located in developed countries, which have all the necessary security and safety measures in order to protect them from external factors and threads. Public concerns regarding safety issues and the possibility of dealing with the impacts of a nuclear accident highlights the importance of protecting these facilities. It is also claimed that most of these states have stable political conditions and they do not have to fight against indigenous terrorist problems. In addition, several public concerns exist regarding to the safety issues of nuclear energy, leading to many difficulties concerning the beginning of constructing such facilities. As a result, the access of such facilities by terrorists is extremely hard and their attack would be probably unsuccessful. The only possibility of having a successful attack to NPPs is in case an aeroplane was flying into them or a group of armed terrorists would take the control over facilities[98]. However, the development of technology is a way to make an attack to nuclear infrastructures possible. For example, a few months ago, a drone was used in order to cause damages to energy infrastructures of ARAMCO in Saudi Arabia[99]. In the United States, the NRC carries out FOF exercises, in order to check the readiness and the safety measures of each nuclear power plant[100]. Such exercises take place every three years. Although these virtual attacks cannot be compared with real attacks, flaws of security systems can be addressed.

Another form of attack to NPPs is cyberattack. In order to extract data from critical internal networks of these facilities, malware designed for hacking are used. India has confirmed the effort of such an attack to Kudankulam nuclear power plant in 2019, the largest operational nuclear power plant in India[101]. The vulnerability of nuclear sector is obvious and serious concerns for the future arise. Although the manipulation of the electric systems that control nuclear reactor is very difficult, it could have negative consequences to the operation of a reactor and it could lead to release of radiation. In the United States attention is increased for cyber security at nuclear facilities. The fact that most counties have aging infrastructure decreases the possibility of such cyberattacks. However, not all states have the same policies and in many cases there is an important lack of regulation for cyber security. The adoption of

[97] Fedorowicz K. J. (2007), The Ten-Thousand Mile Target: Energy Infrastructure and Terrorism Today, Critical Energy Infrastructure Protection Policy Research Series, CCISS p. 1-20

[98] Bodancky D. (2004). Chapter 17: Nuclear Bombs, Nuclear Energy, and Terrorism, *Nuclear Energy: Principles, Practices and Prospects,* Springer, USA, p. 512-514.

[99] The Guardian (2019), Major Saudi Arabia oil facilities hit by Houthi drone strikes. https://www.theguardian.com/world/2019/sep/14/major-saudi-arabia-oil-facilities-hit-by-drone-strikes

[100] U.S.NRC (2019), Backgrounder on Force-on-Force Security Inspections. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/force-on-force-bg.html

[101] E&T (2019). Cyber attack on India's largest nuclear power plant confirmed. https://eandt.theiet.org/content/articles/2019/10/cyber-attack-on-india-s-largest-nuclear-power-plant-confirmed/

regulations and working with technology experts are necessary to deal with cyberattacks[102].

The purpose of a terrorist attack defines the target. If an attack was successful and radiation was released, the results of radioactivity in public health will not be visible immediately. Despite the fact that an attack may be unsuccessful, public opinion will be terrified. If the main aim is to damage economy, then nuclear reactors are not the appropriate target. As there are only 30 states which generate electricity by NPPs and the percentage of electricity produced by them, is not very high comparing to the total power output in the global economy. As a result, such an attack would not have the level of negative impacts they would probably desire in a global level, but it would harm incalculably the area surrounding the NPP.

The aim of an attack can also be the acquisition of radioactive materials (plutonium and highly enriched uranium) for the construction of nuclear weapons. This is one of the reasons why it is believed that terrorist organizations attack to nuclear facilities. The purpose of these actions is to panic and cause social upheaval and the belief that nuclear threat is credible. The threat of a possible attack affects several political decisions. In spite of the fact that most cases of theft are not confirmed, they are a reality. However, terrorist organizations do not have all the necessary equipment, the knowledge and the disposal to use nuclear terrorism. Specialized scientists and experts are necessary for the transportation and operation of nuclear bombs and radioactive materials. However, it is claimed that there are terrorist organizations, such as Al Qaeda, which have tried to recruit scientists in order to create a bomb.

Furthermore, the smuggling of nuclear weapons, the necessary technology and the materials for their production are also important concerns of international community. Smuggling can be an action of organized crime, but most of the times organized crime prefers to make money with limited risk and nuclear smuggling activities are operations of high risk. Russia is an example of such thefts of weapons from their facilities, because of security weaknesses during the 1990s. They tried to cooperate with the USA in order to develop its security measures[103]. Both Russia and Western countries have serious concerns for these incidents.

These radioactive materials can also be used in an alternative way. Their release in nature and the contamination of lakes, rivers and water reservoirs aim to cause a wide range of negative impacts to environment and human lives[104].

To prevent such results, the security of facilities has to be increased. Such attacks can be feasible only at states with less effective security systems, as outsider and insider threats are dangerously high because of the existence of extremist organizations (e.g. Pakistan). It is claimed that the use of nuclear terrorism is possible but groundless. States and international organizations try to prevent the expansion of

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102 NTI, Cybersecurity. https://www.nti.org/about/cyber/

103 Caravelli J. (2008), Nuclear Insecurity: Understanding the Threat from Rogue Nations and Terrorists, Praeger Security International, Westport, Connecticut. p. 15-70.

104 Μπόση Μ. (1999), Όπλα Μαζικής Καταστροφής, *Ζητήματα Ασφαλείας στη Νέα Τάξη Πραγμάτων,* Εκδόσεις Παπαζήση, Αθήνα, p. 170-180

nuclear terrorism. But they have to deal with suspicion of states, as they are afraid of snatching their nuclear weapons. As a result, they deny foreign scientists and specialists access to the facilities. For example, despite U.S.-Pakistani nuclear security cooperation, Pakistan do not allow U.S. experts to access to its NPPs[105]. Security of nuclear weapons and materials is demanding and the international cooperation is necessary to achieve it.

[105] Miller S. et al. (2009), Reducing the greatest risks of nuclear theft & terrorism, *Fall 2009: on the global nuclear future, Vol. 1*, Daedalus- Journal of the American Academy of Arts and Sciences, p. 112-123.
https://www.amacad.org/sites/default/files/daedalus/downloads/09_fall_daedalus_articles.pdf

Chapter 5: The case of China

5.1 General Characteristics

China is one of the most multitudinous countries in the world, having more than 1 billion citizens. As a result, almost 18% of world share is located to its territory[106]. Its economy was based in agriculture for many years, but its industrialization and urbanization increased its energy needs, which had to be covered[107]. The rise of energy demand and population growth the last decades led to the increasing combustion of fossil fuels, especially coal, because of their low prices, in order to prevent the inability to secure energy supplies. Energy production was based to these fuels, causing several negative impacts to the environment. In order to decrease these consequences, changes to its energy mix and energy industry had to be carried out. However, the political conditions in China affected the development of energy industry.

The special features of China are: 1) its population, 2) its political status, 3) the energy needs and the importance of energy security and, finally, 4) the environmental issues. The most important challenges it has to deal with are energy security and climate change.

5.2 Energy and Environmental footprints

Because of the increased energy demand, the electricity consumption of China increased from 603 TWh to 6.349 TWh between 1990 and 2017, according to the IEA[108]. In order to cover these energy needs without disruption, coal was combusted for the electricity production, as it is a fuel with low price. Especially after 2002, its use was rapidly increased since 2012, when a small decrease was noticed because of the simultaneous increase of electricity production by renewable resources. As a result, the CO_2 emissions were almost tripled (from 3.552 Mt to 9.302 Mt) at the same time period, making China one of the greatest emitters globally.

CO_2 emissions cause negative consequences to the environment. Air pollution is one of the most well-known problems of China, especially to urban areas, such as Beijing, where an important percentage of population is living. The concentration of GHG has led to noticeable changes in climate the last decades. The average air temperature has risen by 0.5-0.8 ^oC aggravating the greenhouse effect. Because of higher temperatures and the greenhouse effect, several health problems are caused and the levels of mortality have been risen, especially to elderly. Cardiovascular and respiratory diseases are common because of the extreme weather conditions (e.g. raise of temperature). In addition, climate-sensitive infectious diseases can be affected because of climate change[109].

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106 Worldometers, Population Comparison: China, EU, USA, and Japan. https://www.worldometers.info/population/china-eu-usa-japan-comparison/

107 IEA, Data and Statistics. https://www.iea.org/statistics/?country=CHN&isISO=true

108 Supra note 107

109 Kan H. (2011), Climate Change and Human Health in China, *Environmental Health Perspectives*, Vol. 119, p. 60-61. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3040620/pdf/ehp-119-a60.pdf

In addition, China has to deal with increased water stress. Great amounts of water have to be available in order to produce energy by coal or thermal power generations. North China suffers from water scarcity, but it accounts over the half of its thermal power generation and almost four-firths of coal production and reserves. According to the IRENA, almost 12% of national water withdrawals were accounted to power sector. As a result, these power plants have to be replaced with less polluting options progressively. Renewable energy technologies require less water and they could achieve water and carbon saving. Nuclear energy, despite technological development of the industry, still rises concerns because necessary amounts of water for energy production are great and there are concerns in case of a nuclear accident and its environmental impacts[110].

China has to deal with the challenge of producing energy in an environmental and economically sustainable way. The reduction of GHG emissions is necessary for sustainable development, in order to limit the negative health and environmental impacts. Chinese government had to act to combat climate change. Alternative energy resources was the answer for these concerns and nuclear energy was one of these resources.

5.3 The evolution of nuclear energy

At first, in the middle of the 1950s China developed a nuclear weapons program with the support of the Soviet Union, in order to improve its military power and its political status. Despite the withdrawal of aid from the Soviet Union and the internal financial and political problems, it continued the program managing to test its first atomic bomb in 1964, which was constructed because Mao claimed that if China did not had a bomb, then it would not be a countable military force[111]. Its progress was notable, as it had detonated its first hydrogen bomb until the end of the 1960s, it had launched its first nuclear missile and it constructed its first nuclear submarine. This industry was always affected by politics and the internal political status of China because of the continuous reorganization of the nuclear reactor program by changing leaders. However, the development of nuclear weapons technology led to the evolution of nuclear industry, technology and infrastructure and it influenced the development of civilian nuclear industry.

Although many serious concerns for the development of such a program existed, the civilian nuclear program was put in place when the Cultural Revolution came to an end. The priority of Chinese government was the development of agriculture, industry, defence, science and technology. During the 1970s China started to search for possible cooperation with the United States, France and Germany so as to achieve the development of these sectors by purchasing foreign nuclear reactors'

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[110] IRENA, China Water Risk. Water Use in China's Power Sector: Impact of Renewables and Cooling Technologies to 2030. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_China_Water_Risk_Power_brief_2016.ashx

[111] Xu Yi-chong (2010), Chapter 2: From Bomb to Power. *The Politics of Nuclear Energy in China*, Palgrave Macmillan, UK. p. 17-20

technology and sending scientists to study at the USA. The need of energy was urgent, as economic development was delayed because of lack of electricity. Nuclear energy seemed to be a beneficial alternative choice, in order to avoid the negative impacts of lack of fuels, the volatility of prices and problems to their transportation. However, there were doubts if China could develop it because of its financial condition, the lack of necessary technology, internal conflicts at a political and local level. Furthermore, the internal political status did not allow foreign borrowing and foreign direct investment, which were necessary for the construction of nuclear facilities in order to increase the production of electricity. The only exception was the Daya Bay project, where these traditional restrictions were abandoned by Chinese government so as to achieve nuclear development, despite opposite opinions that preferred the development of other alternative resources in which no foreign capital would be needed. Ten years later (in 1987), its first commercial nuclear power station was constructed[112]. It is obvious that China had developed its nuclear energy projects individually and discontinuously. Its economy was transformed to a more market-driven system. It also managed to design and produce nuclear reactors domestically, using and developing foreign technology.

Despite the interest of China for commercial nuclear energy, its development delayed until 2005, as its strategic plan was short-term. In 2006 a long-term plan (2005-2020) was approved by Chinese government for the first time, increasing its nuclear capacity. Gradually, its nuclear policy became more "aggressive" and it improved its nuclear technology in order to convert it to a safer and more economic efficient form. Planning, approval and licensing of such program is not easy in the case of China because of the involvement of many governmental organizations with several responsibilities[113].

5.4 The present conditions

China has 45 nuclear power reactors in operation, 15 under construction and several about to start construction. They are located to coastal areas, where there are no coalfields. Air pollution from coal-fired plants is the reason to develop nuclear industry. It has developed a closed nuclear fuel cycle policy. It has adapted and it has improved western nuclear technology, managing to become self-sufficient. Its structures were built during last decades, in contrast to NPPs of the USA where the reactors are built over 30 years ago. This is the reason why nuclear generation of China is going to be increased by 2040, according to BP Energy Outlook 2019 edition[114], in order to achieve the goals of international policies for environmental protection and prevention of climate change. However, high levels of water stress in

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[112] Xu Yi-chong (2010), Chapter 2: From Bomb to Power. *The Politics of Nuclear Energy in China*, Palgrave Macmillan, UK. p. 16-45

[113] Zhou Y. et al. (2011). Is China ready for its nuclear expansion? Energy Policy, Vol. 39, Issue 2, p. 771-781. https://www.sciencedirect.com/science/article/pii/S0301421510008025

[114] BP Energy Outlook, 2019 Edition, p. 109. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf

China and the future increasing consumption of water in energy sector, according the IEA, sets nuclear energy as a non-preferable low carbon technology[115].

Figure 15:

Source: World Nuclear Association. Retrieved from https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

Thanks to the development of its nuclear technology, China has managed to construct nuclear reactors. As a result, it develops a policy of exporting nuclear technology affecting its political and diplomatic influence in international arena and acquiring a more determining role in global markets, as Russia does. It targets countries of South America, Africa, Asia and Europe[116]. The construction and the financing of nuclear projects to these countries make them dependent and vulnerable in case of their inability to repay their lending to China.

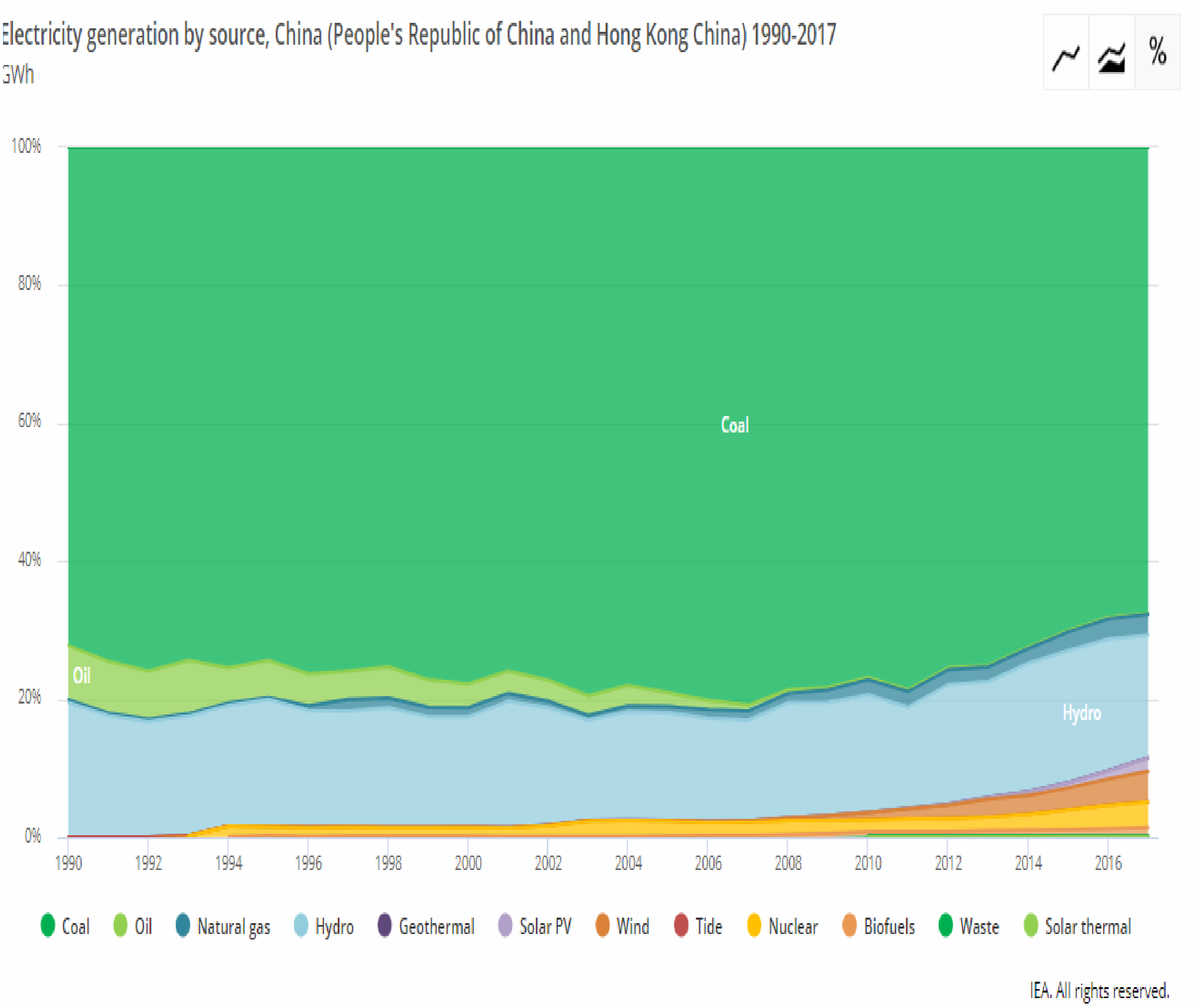
Before the nuclear accident at Fukushima Daiichi, there were lacks to the safety issues of nuclear industry. After the accident, Chinese government realized the importance of safety and a new nuclear safety plan has been approved, according to the IAEA standards. These efforts are complex, because China has multiple types of

[115] Supra note 40
[116] World Nuclear Association (2019), Nuclear Power in China. Retrieved from https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

nuclear reactors and multiple technologies and it has to set multiple standards of safety. Public opinion also affected the rhythm of expansion of nuclear energy, because of the fear caused by Fukushima accident.

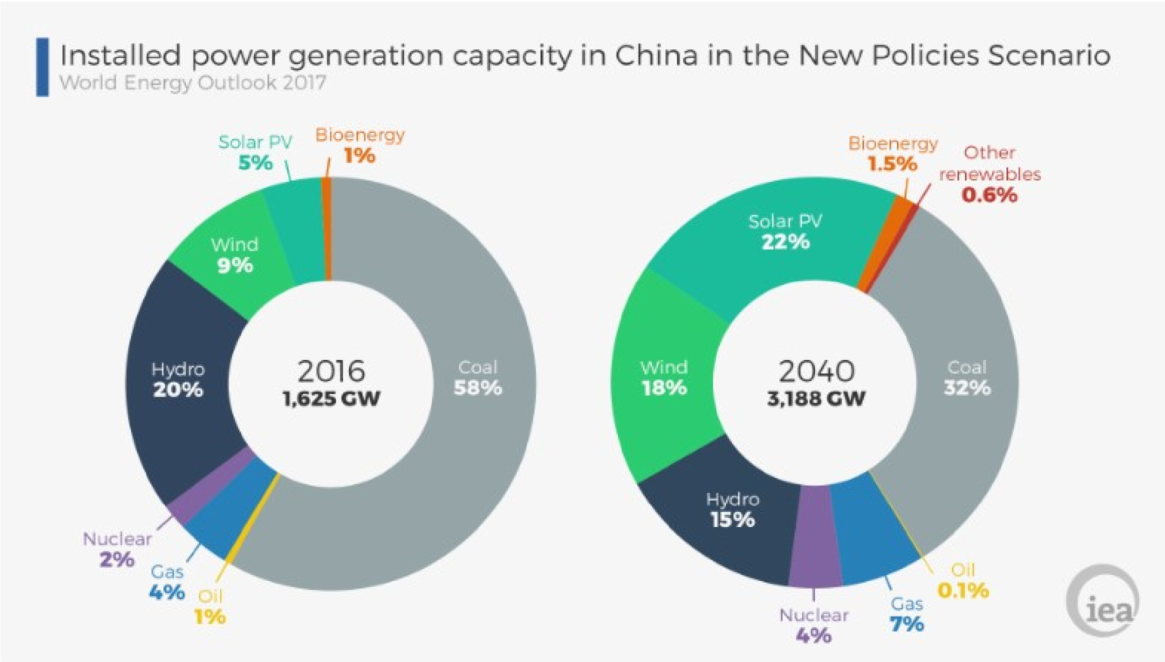
Therefore, nuclear energy remains an alternative choice and it cannot be used as the main pillar of clean energy production in China. According to the IEA, in 2017 coal remains the basic fuel for energy production (67.6%). Renewable resources (hydro-17.8%, wind-4.4%, solar-2%) exceed the rates of nuclear energy in China's energy mix (3.7%). Despite the increase of electricity generation by nuclear power, its percentage is still small comparing to the rate of renewable resources (Figure 16). It is predicted that renewable resources will have a central position in Chinese energy mix for many years. It can be proved by the average investment for power plants and networks in China, according to its New Policies Scenario (Figures 17 and 18). Furthermore, the issue of public acceptance of nuclear energy has a significant position to the expansion of nuclear energy and renewable resources.

Figure 16:



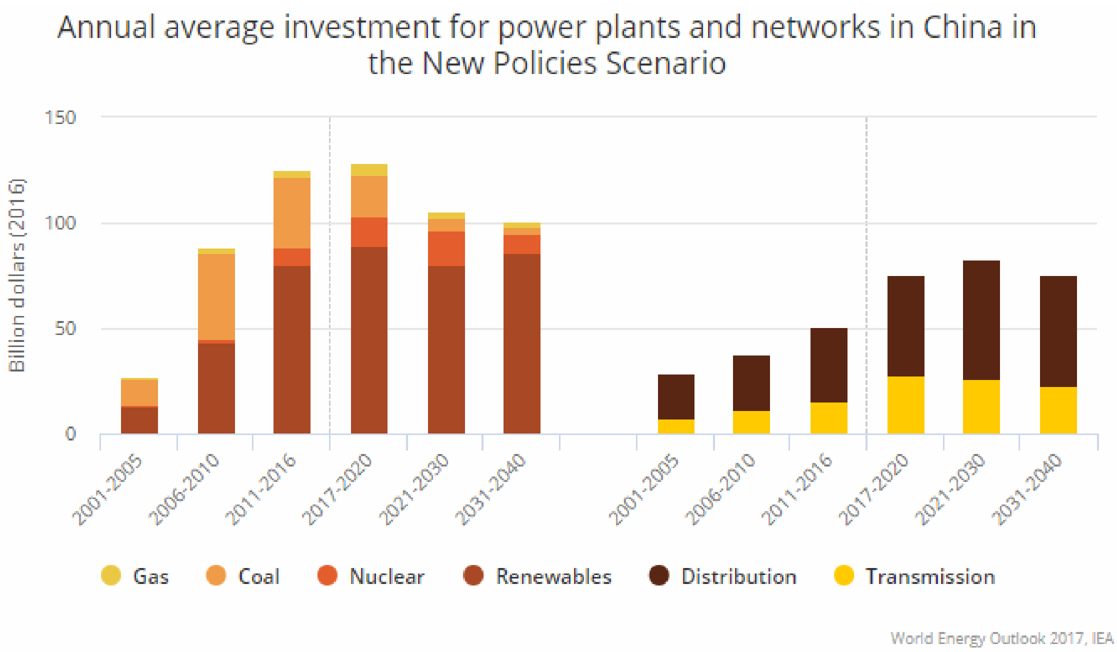
Source: IEA, Data and Statistics. Retrieved from https://www.iea.org/data-and-statistics in 24th November 2019

Figure 17:



Source: IEA. Retrieved from https://www.iea.org/weo/china/#section-2 in 24th November 2019

Figure 18:



Source: IEA. Retrieved from https://www.iea.org/weo/china/#section-2 in 24th November 2019

5.5 China and nuclear weapons

China is one of the NWS and it is estimated that it has a significant number of weapons, despite the efforts of Chinese government not to notify their nuclear power to external factors. It has declared that no-first-use policy has been adopted and that weapons will be used only as a deterrence of an attack. It claims that it tries to adopt a nuclear policy that builds a nuclear force capable of meeting its national security needs.

Their power has created serious concerns to the international arena and the USA are afraid of it. The expansion of Chinese nuclear forces affects their influence in the area, as many US military bases are located to South-eastern Asia. The cooperation of the USA and China during the Cold War was a way to deter a nuclear war against the Soviet Union, to control the military development and power of China and to expand US presence in the region. However, China's independent development increases the concerns of the USA, despite the fact that the second has greater nuclear force, as the US presence is weaken. It is also claimed that China's development may prevent North Korea from implementing its provocative statements, achieving the maintenance of stability and peace at the region[117].

Furthermore, the nuclear relationships of China with other countries determine its strategic relationships. China exports its nuclear technology to other countries. It is the only competitor of Russia, which is the main exporter of nuclear technology globally[118]. Iran and Pakistan are some of the countries China cooperates, despite the fact that these states are outside the Nuclear Non-Proliferation Treaty and they are excluded from trade in nuclear plant or materials.

[117] CSIS (2013), Nuclear Weapons and U.S. – China Relations, p. 1-8. https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130307_Colby_USChinaNuclear_Web.pdf

[118] The Economist (2018), Russia leads the world at nuclear-reactor exports. https://www.economist.com/graphic-detail/2018/08/07/russia-leads-the-world-at-nuclear-reactor-exports

Conclusions

Nuclear energy remains one of the alternative energy resources in the global energy mix. It produces a great amount of energy by a small amount of fuel, ensuring energy security.

It is also a clean form of energy. Less CO_2 emissions are emitted during its production, comparing with other energy industries. Nevertheless, great amounts of water have to be used during electricity production from nuclear power plants. Technology tries to improve the level of water consumption and the environmental footprints of nuclear industry.

On the other hand, the risks of its development delay its expansion. Firstly, its projects are expensive and long-term. Political and economic stability of a state is necessary during the implementation of the project. This is the reason why only a few states have developed commercial nuclear programs. It is an energy industry not affordable and suitable for all states.

In addition, great environmental concerns remain despite the development of technology. Except from water, there are serious environmental and health risks because of nuclear waste and release of radiation. Although technology has developed disposal and reprocessing technic, public opinion is afraid of their future impacts.

Public acceptance is also affected by nuclear accidents. There were only three great accidents in history, but the disasters they caused were determining and they created great fear for nuclear energy usages. The development of nuclear energy was negatively affected by their impacts to human health and environment. Although strict security policies are adopted and technology has developed extra safety mechanisms, there are external factors which cannot be prevented, such as unpredictable natural disasters.

The construction of nuclear weapons is one of the most important risks by a geopolitical aspect. There are efforts of preventing their construction, as impacts of a nuclear war would be disastrous. It is claimed that their possession could prevent possible nuclear attacks and peace and stability would be achieved to the area. However, international system is anarchical and each state desires to be powerful. It cannot be predicted if states possessing nuclear weapons will always be able to act rationally, as there are several factors that define their reactions. There is also the fear of nuclear terrorism. It is not believed to be unlikely, however concerns still exist in an international level.

Taking China as an example for the use of nuclear energy, it seems that there are still obstacles for its wider development. Because of its increased energy needs and the environmental problems it has to deal with, nuclear energy seemed to be a suitable solution. CO_2 emissions can be decreased thanks to nuclear industry, but the amount of water consumed during electricity production does not reduce water stress. Despite the cost of projects, nuclear power plants are constructed. However, the results of Fukushima Daiichi accident decreased its development and serious public concerns arose. As a result, China has adopted policies which promote renewable energy resources to achieve its environmental and energy targets. The number of its nuclear weapons can only be estimated because of its political status. Although it has declared a no-first-use policy, there are still doubts in an international level. Furthermore, the development of its nuclear technology and the fact that China exports it to other nuclear states threads the position and power of other states in Asia and global market.

In conclusion, nuclear energy can be partly beneficial for the environment. It can prevent negative impacts of climate change. Nonetheless, its environmental and health risks and the nature of international relations will not stop affecting its position in the energy mix in the future.

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