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Title of Thesis: "Nuclear Power: Is it possible to be used as a transitory fuel during energy transition? What will be the geopolitical effect?"

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

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I would like to express my sincere gratitude to my supervisor, Professor Athanasios Platias, whose valuable guidance was crucial for the completion of this study.

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Contents

Abstract

This study's purpose is to explore whether nuclear power could be used as a transitory fuel during the Green Transition. It examines the advantages and disadvantages of nuclear power, as well as the opportunities and challenges for its expansion in light of the turbulent geopolitical circumstances that the world currently faces. It also discusses whether new technologies, such as small modular reactors, could be proven crucial to expanding the share of nuclear power in the global energy mix. Finally, this analysis uses the main theories of international relations and the practicality of game theory to predict if and to what extent the expansion of civilian nuclear power could lead to conflicts.

Keywords: *Nuclear energy, The Green Transition, advantages of nuclear, disadvantages of nuclear power, SMRs, geopolitical tensions, International relations, Game Theory*

INTRODUCTION

I. Purpose and Methodology

This thesis was created in the context of the master's Program "MSc in Energy: Strategy, Law and Economics" of the Department of International and European Studies of the University of Piraeus.

Its purpose is to describe in depth the benefits and disadvantages of the civilian use of nuclear power along with the challenges that come with a potential expansion of its exploitation during an apparent nuclear renaissance. At the same time, it provides a broader view of the existing and possibly future potential nuclear geopolitical alliances under the prism of the current turbulent geopolitical circumstances.

For the realization of this study, both qualitative and quantitative data were used, including but not limited to, statistics, scientific papers and articles, as well as pictures depicting different types of reactors in operation to enhance the understanding of the public. It should also be noted that international political theories, as well as game theory, and real-world examples were used to provide both a theoretical and a practical explanation in regards to whether nuclear power could lead to proliferation and whether this proliferation could lead to a nuclear war.

II. Guiding Questions

Through profound research, this study will attempt to answer the following questions:

- What is nuclear energy, why is it controversial and how did it rise to prominence?
- What are the main reasons behind the fact that some countries are willing to construct nuclear plants, while others still disapprove of nuclear energy?
- What are the current trends that justify the nuclear renaissance?
- What are the greatest threats for the expansion of nuclear energy?

- Are there any countries that use nuclear energy as a primary fuel? Which ones produce the most/the least amount of nuclear generated electricity?
- Which countries are expected to lead nuclear power generation in the coming years?
- Is proliferation possible? If yes, what is a conflict inevitable?

1. CHAPTER ONE: WHAT IS NUCLEAR ENEREGY AND HOW DID IT RISE INTO PROMINENSCE

1.1 What is nuclear energy

Nuclear energy is a form of energy released from the core of atoms (nucleus) and can be produced either by fission or fusion[1].

Nuclear fission was accidentally discovered in Germany in 1938[2]. It is a reaction where a neutron slams into a larger atom, forcing it to split into smaller atoms while releasing energy in the form of heat and radiation (figure 1)[3]. During this phenomenon, more neutrons are released, causing the procedure to repeat itself[4].

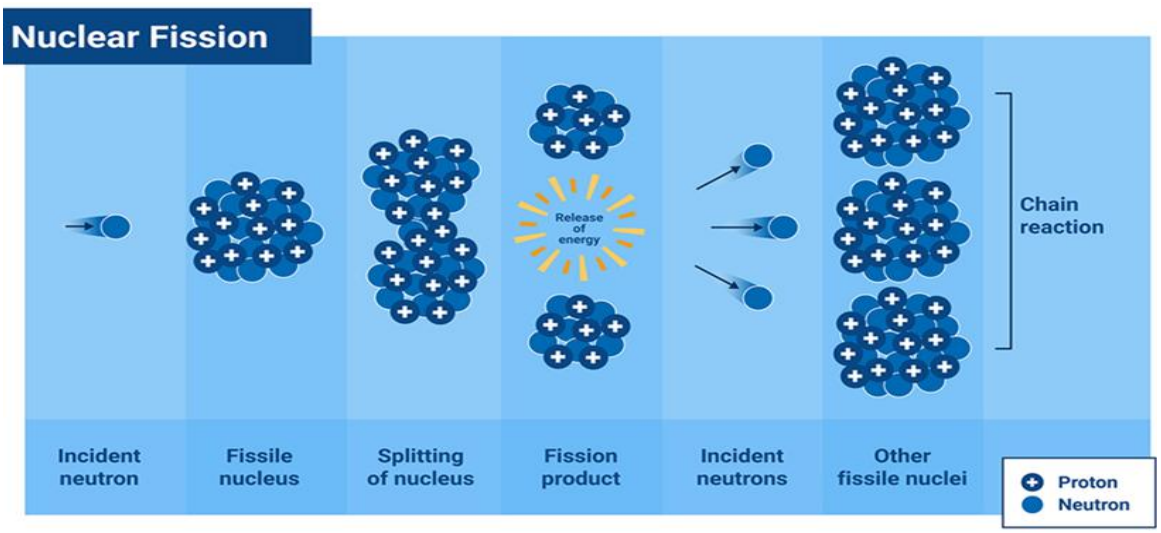

Figure 1: The process of Nuclear Fission

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[1] Galindo, Andrea. 2024. "What Is Nuclear Energy? The Science of Nuclear Power." IAEA, June 18, 2024. https://www.iaea.org/newscenter/news/what-is-nuclear-energy-the-science-of-nuclear-power.

[2] "The Discovery of Nuclear Fission." n.d. Accessed June 10, 2025. https://www.mpic.de/4469988/die-entdeckung-der-kernspaltung.

[3] U.S. Energy Information Administration (EIA) Nuclear explained

[4] "Fission and Fusion: What Is the Difference?" n.d. Energy.Gov. Accessed June 10, 2025. https://www.energy.gov/ne/articles/fission-and-fusion-what-difference.

Source: Andrea Galindo upd. 2025 'What is Nuclear Energy? The Science of Nuclear Power', n.d. International Atomic Energy Agency https://www.iaea.org/newscenter/news/what-is-nuclear-energy-the-science-of-nuclear-power

In contrast, in nuclear fusion (figure 2) two lighter atoms combined to form a heavier one[5]. The sun and stars are powered by this reaction.

Since a massive amount of energy is released during fusion, replicating the reaction on earth at an industrial scale could potentially meet the increasing energy demand worldwide and amplify power production.[6] However, as of 2025, such a development has not yet occurred, despite DOE National Laboratory achieving fusion ignition in 2022[7].

Given that fusion has not been exploited yet, this study will focus on nuclear fission.

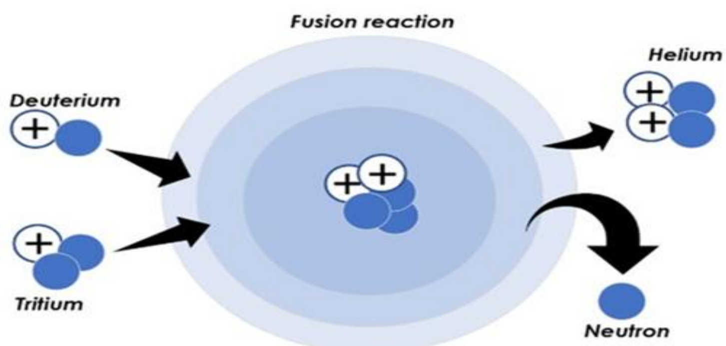

Figure 2: The process of Nuclear Fusion

Source: Irena Chatzis, Matteo Barbarino 'What is Fusion, and Why Is It So Difficult to Achieve?' n.d. , International Atomic Energy Agency, May 2021 https://www.iaea.org/bulletin/what-is-fusion-and-why-is-it-so-difficult-to-achieve

[5] "What is Nuclear Fusion?" n.d. IAEA, Accessed June 10, 2025. https://www.iaea.org/newscenter/news/what-is-nuclear-fusion

[6] "DOE Explains...Fusion Reactions." n.d. Energy.Gov. Accessed June 14, 2025. https://www.energy.gov/science/doe-explainsfusion-reactions.

[7] "DOE National Laboratory Makes History by Achieving Fusion Ignition." 2022. Energy.Gov. December 13, 2022. Accessed June 14, 2025. https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition.

1.2. History of Nuclear Energy

1.2.1 The Frisch-Peierls Memorandum

Though the story of nuclear energy unofficially begins with the discovery of uranium in 1787[8] it took scientists over a century to make substantial progress in the fields of atomic radiation and nuclear fission. This milestone was to be hit during 1935-1945, when scientists were working on developing the atomic bomb[9].

To elaborate, fission was discovered in Germany in 1938. However, two years later, physicists Otto Frisch and Rudolf Peierls made a breakthrough by confirming the feasibility of the atomic bomb in the so-called "Frisch-Peierls Memorandum"[10]. The paper also highlighted the mightiness of the bomb compared to conventional weapons, stressing that if misused, countless casualties would occur.

The memorandum ended up at the MAUD Committee, which was secretly founded in London to verify its finding. A year later, in July 1941, the Committee prepared two reports on the use of uranium: one focused on military applications and the other on civilian uses.

More specifically, fearing that Germany was also developing an atomic bomb, the committee secretly recommended that both London and Washington intensify the bomb project. However, even though such a decision was made by the UK, the US seemed more eager to exploit uranium for peaceful purposes, despite declaring that the bomb project was their priority. Nonetheless, that changed when, on December 7th, 1941, the Japanese attacked Pearl Harbor, forcing Americans to join the war.

[8] "Nuclear Fuel Facts: Uranium." n.d. Energy.Gov. Accessed June 14, 2025. https://www.energy.gov/ne/nuclear-fuel-facts-uranium.

[9] "Outline History of Nuclear Energy - World Nuclear Association." n.d. Accessed June 14, 2025. https://world-nuclear.org/information-library/current-and-future-generation/outline-history-of-nuclear-energy.

[10] "Britain's Early Input - 1940-41 - Nuclear Museum." n.d. Nuclear Museum. Accessed June 14, 2025. https://ahf.nuclearmuseum.org/ahf/history/britains-early-input-1940-41/.

1.2.2 The Manhattan Project

The attack in Pearl Harbor became a catalyst for US to take a more substantial role on the bomb project. This resulted to a huge secret research and development program, known as «The Manhattan Project». The program, directed by American Major, General Leslie Groves was led by Washington in collaboration with London and Ontario. Its first headquarters were in Manhattan, from where it took its name. The operations however ended up primarily taking place in Hanford, Los Alamos, and Oak Ridge locates in Washington, New Mexico and Tennessee respectively. Nuclear physicist J. Robert Oppenheimer was the director of the Los Alamos Laboratory.[11]

In August 1943, British Prime minister W. Churchill and American President F. D. Roosevelt secretly signed an Agreement in Quebec, Canada. The Agreement required that the signatories closely cooperate to develop nuclear weapons. Neither party would use these weapons against each other, share nuclear related information or target another state without having reached a consensus with the other party.

On July 16, 1945, after having spent 2.2 billion dollars on the project, Washington successfully conducted its first atomic test in New Mexico[12]. However, by this time Berlin had already surrendered, bringing the world one step closer to the end of the war. The last predominant obstacle towards this goal was Japan. The idea of putting a brutal stop on its revisionism was predominantly in the minds of the Manhattan Project leaders. As a result, on August 6 and 9 1945, two bombs were dropped on Hiroshima and Nagasaki, killing an estimate of 100.000 people, forcing Japan's surrender.

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[11] F. G. Gosling, The Manhattan Project: Making the Atomic Bomb (DOE/MA-0001; Washington: History Division, Department of Energy, January 1999), 9.

[12] Metcalfe, Tom. 2024. "What Was the Manhattan Project?" Scientific American, February 20, 2024. https://www.scientificamerican.com/article/what-was-the-manhattan-project/.

1.2.3 The Atomic Energy Act of 1946

The severe repercussions of the Manhattan Project cultivated a fear for potential nuclear apocalypse in case of proliferation. The United States especially, having used nuclear weapons against another state, have witnessed firsthand the associate dangers and dreaded the prospect of more countries obtaining nuclear technology. In this regard, they adopted strict measures against the potential spread of nuclear weapons.

Under these developments US President Truman signed the Atomic Energy Act in 1946 which was sponsored by the Democrat Senator Brien McMahon and set into implement on January 1, 1947. Under the Act the spread of nuclear equipment on the one hand, and what was defined as scientific «restricted data» on the other, was made extremely difficult. Section 10 (b) (1) of the Act defined restricted data as *«all data concerning the manufacture or utilization of atomic weapons, the production of fissionable material or the use of the latter in the production of power. »*[13] These data were to be controlled by Atomic Energy Commission. The latter was charged with the task of allowing such information to be spread sparingly and on specific conditions. Penalties for breaching these conditions could range between high fines to even death.

Two years later. on 29 August 1949, Soviet Union proceeded to test its first nuclear bomb, code-named "First Lightning" in Kazakhstan[14]. Similarly, Rusia tried to restrict the proliferation of nuclear weapons to the countries under its influence, but as we will examine later to no avail[15].

At the same time, New Delhi ordered the establishment of the Atomic Energy Commission of India in 1948. This development spiked fears in Washington, because Paris was considered an attractive market by New Delhi, for the purchase of nuclear equipment. The US did not however

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[13] De Blasio, Nicola, Richard Nephew, and Center on Global Energy Policy. 2017. "THE GEOPOLITICS OF NUCLEAR POWER AND TECHNOLOGY." Journal-article. COLUMBIA SIPA. https://www.energypolicy.columbia.edu/sites/default/files/energy/The%20Geopolitics%20of%20Nuclear%20Power%20and%20Technology%20033017.pdf.

[14] International Campaign to Abolish Nuclear Weapons, Nuclear Weapons History

[15] Eliza Gheorghe; Proliferation and the Logic of the Nuclear Market. International Security 2019; 43 (4): 88–127. doi: https://doi.org/10.1162/isec_a_00344

want to allow France to enter let alone dominate a huge lucrative and highly ambiguous market in Asia. For the reason, the US Atomic Energy Commission and the AECI, signed an Agreement in the same year, according to which Washington would share with New Delhi scientific knowledge, regarding the proper exploitation nuclear research centers. Three years later in 1951, Indian government disclosed its plans concerning the creation of a small nuclear reactor for research and isotope production. During the same year 1951, the country, opted to close a deal with France, for the creation of a research reactor, which would operate under the authority of the French Atomic Energy Commission, after a careful study would be conducted.

UK became the third country to test nuclear weapons on 3 October 1952, at Montebello Islands in Australia. Other tests were later conducted at Maralinga and Emu Fields.

It was evident that the USA's atomic power monopoly has ceased to exist.

1.2.4 «Atoms for Peace»

Dwight Eisenhower's presidency, which commenced in 1953, was a pivotal moment for the development of nuclear energy.

Though the new president understood the dangers of atomic weapons, he also did not disregard the benefits of nuclear power. Therefore, he was more willing to share nuclear equipment and scientific knowledge with other states. He believed that, providing such transactions take place, in the absence of ill intentions, more chances for international cooperation would occur. This could subsequently lead to avoiding atomic arm races.

In this regard, during his famous speech called «Atoms for Peace» (Figure 3) the American President stated that humanity must discover *«the way by which the miraculous inventiveness of* *man shall not be dedicated to his death but consecrated to his life»*[16] referring to the need of using nuclear technology for peaceful purposes that could help mankind[17].

The speech, which initiated a friendlier approach towards nuclear power, led to an amendment of the Atomic Energy Act in 1954, the creation of IAEA in 1957, which through a series of safeguards aimed to deter the diversion of nuclear material from peaceful use by maximizing the risk of early detection, and the Treaty on the Non-Proliferation of nuclear weapons.

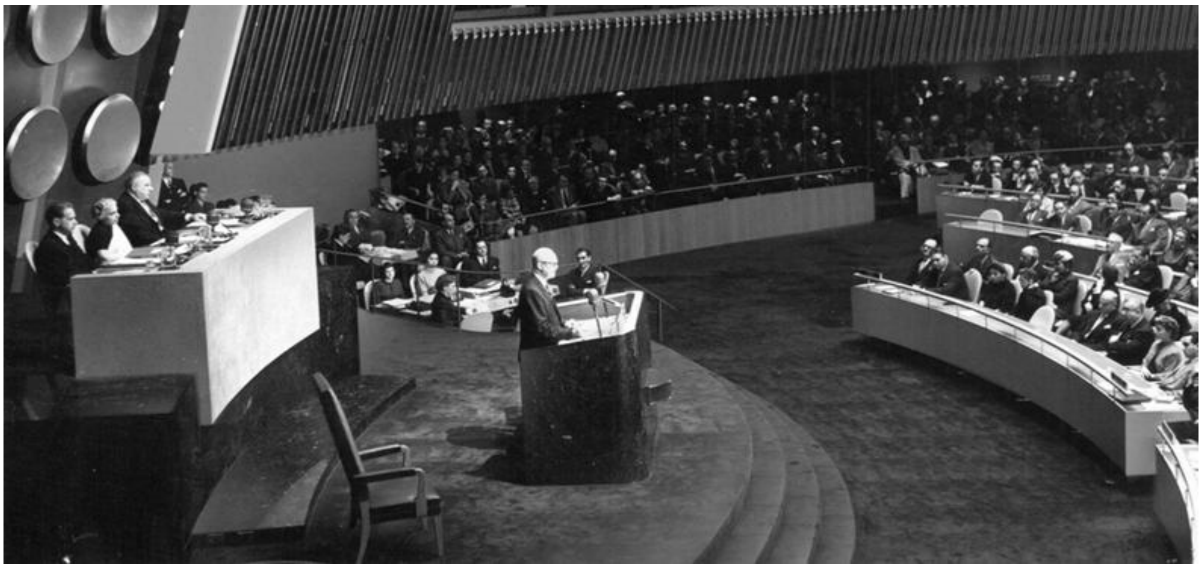

Figure 3: Eisenhower's Atoms for Peace speach at the UN General Assembly

Source: "60 Years of "Atoms for Peace", IAEA, 6 December 2013, https://www.iaea.org/newscenter/news/60-years-atoms-peace

At the same time, the Soviet Union constructed its first nuclear power reactor. This was an important development since it set the foundation for the USSR's nuclear clientele especially among states within its sphere of influence.

[16] Richard G. Hewlett and lack M. Roll, ATOMS for PEACE WAR (1956-1961), Eisenhower and the Atomic Energy Commission

[17] "Atoms for Peace | Eisenhower Foundation." n.d. Accessed June 15, 2025. https://eisenhowerfoundation.net/primary-source/atoms-peace

Coincidently in Europe the European Atomic Energy Community was established in March 1957 and associated with the Treaties of Rome in 1958 aimed to form a common market for the development of the peaceful uses of atomic energy[18].

1.2.5 The Non-Proliferation Treaty

NPT, though not completely successful, is considered one of the most important and impactful international treaties which favored the development of nuclear energy while simultaneously curbed the mindless spread of atomic weapons[19].

Its basic principles can be found in Articles I, II, III, IV and VI of the Treaty. These provisions recognize each nation's right to use nuclear energy for civilian only purposes (Article IV). In this regard, transferring nuclear material would be permitted, on condition that the latter would carry the approval of the IAEA, after the later implemented several safeguards to ensure the civilian purpose of the material. (Article III). Moreover, to prevent nuclear proliferation, countries with nuclear weapons shall not help non-nuclear weapon states to obtain such weapons or transfer weapons to them (Article I, Article II). At the same time, nuclear weapon countries would be bound to initiate a dialogue, aiming to nuclear disarmament[20].

Nations that wanted to participate in the Treaty were able to sign it in 1968; however, it did not enter into force until 1970. Twenty-five years later, NPT was extended indefinitely, and its scope has been widened to include undeclared nuclear activities.

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[18] "Nuclear Power in the European Union - World Nuclear Association." n.d. Accessed June 15, 2025. https://world-nuclear.org/information-library/country-profiles/others/european-union.

[19] Schumann, Anna. 2023. "Fact Sheet: Nuclear Non-Proliferation Treaty (NPT)." Center for Arms Control and Non-Proliferation. June 29, 2023. Accessed June 15, 2025. https://armscontrolcenter.org/fact-sheet-nuclear-non-proliferation-treaty-npt/.

[20] Cgep, Columbia |. 2025. "Why The United States Should Remain Engaged on Nuclear Power: Geopolitical and National Security Considerations." Center on Global Energy Policy at Columbia University SIPA | CGEP. May 20, 2025. Accessed June 15, 2025. https://www.energypolicy.columbia.edu/publications/why-united-states-should-remain-engaged-nuclear-power-geopolitical-and-national-security/.

As of right now, the Treaty counts 191 member-states. More countries have ratified the NPT than any other agreement of such nature[21].

1.2.6 The case of India -The creation of NSG

Even though the NPT was a decisive step to reduce the dangers of proliferation, it was not enough to completely wipe it off. One of the most prominent examples of the Treaty's inadequacy to fully prohibit the spread of nuclear weapons was the case of India, which conducted its first nuclear weapon test in on May 18, 1974, with the code name «Smiling Buddha »[22].

However, to understand how India managed to become a nuclear weapon state, besides the international caution, we must take things to the start, and more specifically in the 1950's. During this time Canada agreed to assist India in the construction of a research reactor and the US agreed to supply the facility with the heavy water for its operation. The Agreement however predated the existence of the IAEA and the NPT, and the facility began operations without international safeguards applied to it. Safeguards were never applied to the reactor later either and India never joined NPT. Consequently, even though New Delhi promised not to use nuclear technology for any other than civilian purposes, it still proceeded to test nuclear weapons in 1974, sparking new fears regarding proliferation.

However, when talking about India, someone should not override the fact that New Delhi was also able to become an NWS also by exploiting the opportunities in nuclear market, because of the intense rivalry between US and USSD. Particularly, by manipulating suppliers, India managed to obtain enriched, rather natural uranium, at less cost and by more flexible terms. Also, given that China proceeded to conduct its first nuclear test in 1968, it is not unlikely, that India's

[21] "Treaty on the Non-Proliferation of Nuclear Weapons (NPT) – UNODA." n.d. Accessed June 15, 2025. https://disarmament.unoda.org/wmd/nuclear/npt/.

[22] K, Ankit. 2024. "50 Years of Pokhran I: Revisiting India'S Peaceful Nuclear Explosion." Orfonline.Org. May 30, 2024. Accessed June 15, 2025. https://www.orfonline.org/expert-speak/50-years-of-pokhran-i-revisiting-india-s-peaceful-nuclear-explosion.

ambition to become NWS, was accelerated for safety reasons, against potential threating actions of their better prepared neighbors.

Following New Delhi's nuclear test the Nuclear Supplier Group (Canada, West Germany, the UK, Japan, France and USSD), was formed in 1974. Its purpose was to enhance the controls regarding exports of nuclear material and technology, to ensure that history would not repeat itself.

The group published a Triger List of nuclear items, which had to be transferred under specific conditions. NSG also published measures for acceptable nuclear transfers, with special caution to ENR. Fourteen years later the group issued a Dual Use List. This List consisted of items with both nuclear and non-nuclear applications, whose exports demanded cautious handling.

Today NSG is the premiere multilateral nuclear export control forum. It establishes the basic framework for standards regarding export controls that the major suppliers must comply with.

Simultaneously the US itself decided to take a more cautious approach regarding nuclear cooperation with countries that did not have nuclear weapons and later forced the rest of the NSG to adopt the reforms that Washington made unilaterally. Such developments on the one hand highlighted the leading role that Washington held in the group, but on the harmonized nuclear practises among the major supplier, against the proliferation of nuclear weapons. In this regard the 1978 Non-Proliferation Act permitted cooperation with NNWS on condition that the later fully accepted IAEA's guidelines. This measure was introduced as response to New Delhi, successfully managing to obtain nuclear weapons, by dismissing the safeguards of IAEA. Later this provision was adopted by the NSG, after much pressure from the US.

1.2.7 The Three Mile Island and the Chernobyl disasters

The Three Mile Island power station in Pennsylvania had two pressurized water reactors, TMI-1 and TMI-2. TM-1 had been successfully operating for almost five years by 1979 and continued to do so for 40 years after the disaster, until it was shut down in 2019. Such was not the case however with TM-2.

More specifically on 28 March 1979 a cooling malfunction in TM-2 caused part of its core to melt leading to its destruction while operating at almost full capacity[23].

Surprisingly, the disaster left zero casualties behind. Furthermore, according to extensive research conducted after the incident, it was inferred that not enough radiation was released into the atmosphere to directly harm the health of those who lived near the plant[24]. Furthermore, as a result of the low levels of radiation, the environmental impact of the disaster has been characterized as minimal. However, the confusion and misinformation following the disaster fueled the fears regarding the safety of nuclear energy[25]. These fears only amplified when seven years later, a new devastating accident took place in USSD.

On 26 April 1986 the Four RBMK reactor of the nuclear power plant in Chernobyl went out of control during a test at low power, which resulted in an explosion that destroyed the reactor building[26]. It was estimated that the disaster itself claimed the lives of 31 people, yet up to 4.000 could have eventually succumbed due to thyroid and other types deriving from radiation exposure[27]. Additionally, approximately 350,000 people were evacuated.

On the other hand, the disaster had a profound environmental impact as well. More specifically contamination by radioactive material was spread in Ukraine, Belarus and Russian Federation while radionuclides from the plant were measurable in all countries of the northern hemisphere[28].

In whole, the disaster curbed public acceptance toward nuclear energy and new fears regarding its safety were spread among civilians.

Five years later, the collapse of USSR and the actions of Sadam Hussein, would lead to new developments regarding nuclear commercial activity.

[23] GPU Nuclear Corp., 10 briefing papers, 1999, Nuclear Energy Institute, Nuclear Energy Overview 08/05/2000

[24] Nuclear Energy Institute, Fact Sheet, Lessons From the 1979 Accident at Three Mile Island

[25] "Crisis Contained, The Department of Energy at Three Mile Island," by Philip L Cantelon and Robert C. Williams, 1982.

[26] “Frequently Asked Chernobyl Questions.” n.d. IAEA. Accessed June 10, 2025. https://www.iaea.org/newscenter/focus/chernobyl/faqs.

[27] Gray, Richard. 2022. “The True Toll of the Chernobyl Disaster.” February 28, 2022. Accessed June 10, 2025. https://www.bbc.com/future/article/20190725-will-we-ever-know-chernobyls-true-death-toll.

[28] “The Chornobyl Accident.” n.d. United Nations: Scientific Committee on the Effects of Atomic Radiation. Accessed June 10, 2025. https://www.unscear.org/unscear/en/areas-of-work/chernobyl.html.

1.2.8 The Additional Protocol

The collapse of the USSR in 1991 marked the end of a prolonged period of bipolarity and political turmoil between the two nuclear superpowers. However, it coincided with a time when Saddam Hussein's Iraq seemed to be significantly ahead in the development of nuclear weapons compared to what the West had previously believed.

These events triggered new fears regarding nuclear proliferation. It was therefore decided that inspection authorities would be strengthened. The creation of the voluntary Additional Protocol allowed IAEA inspectors better access to a state's nuclear fuel cycle, manufacturing and import locations, as well as environmental samples beyond declared locations[29]. The document also contained special provisions regarding export controls of dual-use items. At the same time, NSG began to require IAEA safeguards countrywide before any nuclear transfers could be conducted.

Nonetheless, these efforts were misinterpreted by developing states. They argued that they were deliberately excluded from the nuclear market, allowing the developed world to maintain the advantages of an oligopoly. Consequently, attempts to implement universal standards for nuclear practices faltered, as different countries adopted varying standards for cooperation. A notable example is the "gold standard" for nuclear cooperation between the US and the UAE. This agreement permitted Abu Dhabi to receive nuclear material, technology, and scientific knowledge from Washington, contingent upon its decision to forgo domestic uranium enrichment and the reprocessing of spent fuel, as well as to sign the IAEA's Additional Protocol.[30]

1.2.9 Fukushima Nuclear accident

On 11 March 2011, a huge earthquake of 9.0 magnitude struck Japan, triggering a devastating tsunami. The ordeal resulted in 18,000 people losing their lives or being listed missing[31]. The

[29] Manseok Lee Michael Nacht, Challenges to the Nuclear Non-Proliferation Treaty, Strategic studies quarterly, 2020 page 96

[30] "US-UAE 123 agreement enters into force". Embassy of the United Arab Emirates on US

[31] Pletcher, Kenneth, Rafferty, and John P. 2025. "Japan Earthquake and Tsunami of 2011 | Facts & Death Toll." Encyclopedia Britannica. June 12, 2025. Accessed June 16, 2025. https://www.britannica.com/event/Japan-earthquake-and-tsunami-of-2011.,

tsunami also struck the Fukushima nuclear power plant, leading to a horrendous disaster. As a result, half a million people were displaced.

The whole situation appalled international community, with many countries reconsidering the expansion of their nuclear fleet[32]. Consequently, even though in 2021 UN report no direct health effects because of the disaster[33] nuclear investments have already slowed down to minimum.

1.2.10 Recent Developments -A Nuclear Renaissance?

The most notable development following the surge of nuclear activity that ensued after the Fukushima disaster was the endorsement of Iran's nuclear agreement (JCPOA) by the UN Security Council on July 20, 2015. However, three years later, on May 8, 2018, President Donald Trump announced the United States' withdrawal from the JCPOA[34], which sparked new tensions and created an ongoing dilemma regarding the dangers associated with Tehran's nuclear program.

However, the first real chance for the expansion of nuclear power was given when global interest began to shift toward alternative sources of energy. With the impact of climate change becoming increasingly difficult to ignore, states decided to take joint action against it. In this regard, the Paris Agreement, which entered into force on November 4, 2016[35], aimed to prohibit an increase in average global temperature of more than 1.5°C by the end of the century.[36] Another important milestone for the climate friendly policies came a few years later, when governments worldwide implemented protective measures to prevent the spread of Covid-19. During this period, GHG

[32] Nam, Hoseok, Satoshi Konishi, and Ki-Woo Nam. 2021. “Comparative Analysis of Decision Making Regarding Nuclear Policy After the Fukushima Dai-ichi Nuclear Power Plant Accident: Case Study in Germany and Japan.” Technology in Society 67 (September): 101735. https://doi.org/10.1016/j.techsoc.2021.101735.

[33] “UNSCEAR 2020/2021 Fukushima Report - Frequently Asked Questions and Answers.” n.d. United Nations: Scientific Committee on the Effects of Atomic Radiation. Accessed June 11, 2025. https://www.unscear.org/unscear/en/areas-of-work/fukushima-report-faq.html.

[34]European Council, Council of EU, Iran's nuclear agreement

[35] United Nations. n.d. “The Paris Agreement | United Nations.” Accessed June 11, 2025. https://www.un.org/en/climatechange/paris-agreement.

[36] European Council, Council of European Union, Paris Agreement on climate change

fell to record lows across the globe. Although this decline was short lived[37], it reinforced the belief that achieving an eco-friendlier approach was possible.

Nonetheless, following Moscow's 2022 invasion of Ukraine, there was a brief lull in the conversation about the green transition. As a result, European and other Western governments decided to impose sanction on energy companies, crude oil, petroleum products, and other fossil fuels from Russia[38] and to reduce imports of Moscow's natural gas. This situation resulted in emergency measures that prolonged the use of coal to ensure security of supply.

Discussions about alternative methods for producing clean energy quickly remerged, however. It was then that ambitions about expanding the use of nuclear power formally started to reappear. For instance, in April 2023, the US, UK, Japan, Canada, and France formed a nuclear alliance on the sidelines of the G7, which the British Energy Secretary Grant Shapps said was aimed at pushing Putin out of the nuclear fuel market entirely.[39] In December these nations committed $4.2 billion to develop a secure, reliable global nuclear energy supply chain, mainly focused on enhancing enrichment and conversion capacity in the West.

In chapters 2 and 3 we will analyze the advantages and disadvantages of nuclear power, and also what to expect if it expands further.

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[37] United Nations. n.d. "No, The Pandemic Did Not Help Climate Action | United Nations." Accessed June 11, 2025a. https://www.un.org/en/desa/no-pandemic-did-not-help-climate-action.

[38] European Council, Council of European Union, EU sanctions against Russia explained

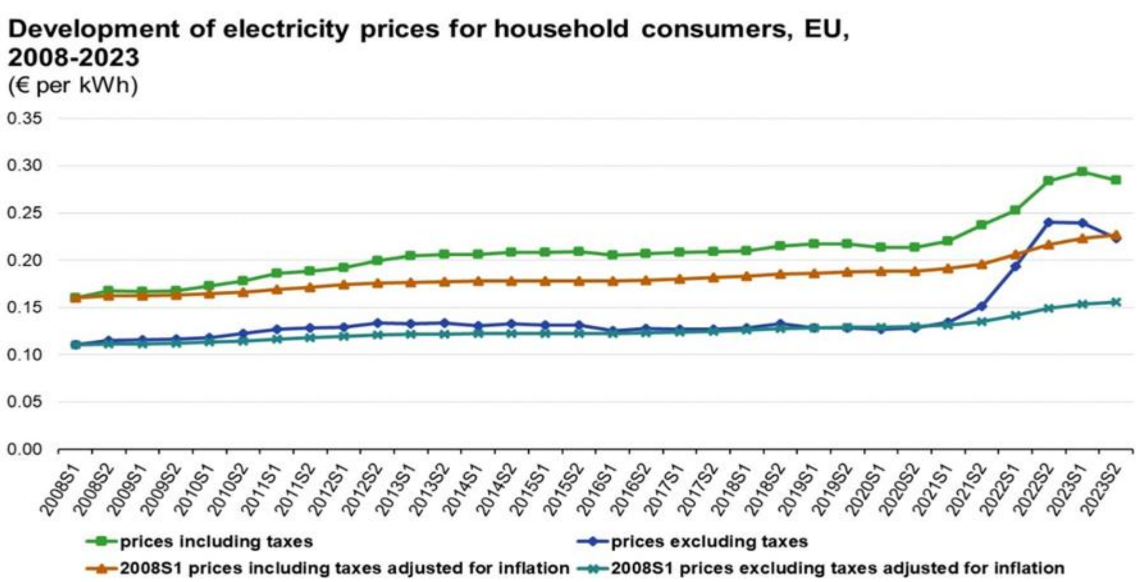
[39] Smyth, Jamie. 2024. "Security Concerns Fuel Nuclear Energy Renaissance." Financial Times, March 21, 2024. https://www.ft.com/content/9632bf6d-d3c8-4cf8-aab5-3e15b8869d8c.

2. CHAPTER TWO: ADVANTAGES OF NUCLEAR POWER

2.1 Energy independence and security

Russian invasion of Ukraine worked as a catalyst to restrict EU's dependency on Moscow's energy exports altogether. For instance, even though natural gas was not yet included in the list of sanctioned products, the share of Russia's pipeline gas in EU imports dropped from over 40% in 2021 to about 8% in 2023. For pipeline gas and LNG combined, Russia accounted for less than 15% of total EU gas imports[40]. In this regard, projections point to a further fall to 13% in 2025 with the end of the Russian gas transit via Ukraine (European Commission, May 2025)

Nonetheless this development did not come without severe repercussions. Given EU's obscene reliance on Moscow's energy, efforts to diversify the energy imports disrupted the supply chain, leading to an unprecedent increase in electricity prices during the first months of the invasion (figure 4)[41].



[40] "Where does the EU's gas come from?" n.d European Council, Council of European Union, Accessed June 12, 2025

[41] European Council, Council of European Union, Energy price rise since 2021

Figure 4: Depiction of the development of electricity prices for household consumers in EU in €/kWh, during 2008-2023

Source: "Electricity price statistics", Eurostat (upd, October 2025) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statisticst

At regional level EU tried to make the most of this unpleasant situation. More specifically the Council adopted three Regulations in 2022 (Regulation EU 2022/2576, Regulation EU 2022/2577, and Regulation EU 2022/2578) to enhance solidarity between member states, accelerate the deployment of renewable energy and protect EU citizens from excessively high energy prices[42]. Especially the latter was of paramount importance as it saved millions of households from bankruptcy.

However, though Brussels pleaded for a more moderated use of energy and preached in favor of Renewable Energy Sources, many capital-intensive RES projects became tasteless to investors, amidst the chaos that prevailed. As a result, many EU governments decided to choose the fastest, but not the most sustainable way to ensure security of energy supply. Athens for instance passed in July 2022, an emergency legislation according to which the lifespan of lignite plants operated by PPC, that were to close by 2025, was extended for three years[43]. Additionally, lignite generation was allowed to increase by up to 50%.

Furthermore, certain gas-fired plants were also required to enable switching to diesel, while DEPA Commercial proceeded to sign an agreement with France's TotalEnergies to secure LNG supplies.

It is safe to infer that such measures would not have been selected had other low emission-power generating systems, including nuclear power plants, been deployed earlier.

Specifically, nuclear power plants could provide countries with high quality electricity, while simultaneously causing relatively small impact on the environment compared to gas and of

[42] In January 2024, it was decided that the measures be prolonged for one more year. See more at European Council, Council of European Union, Prolongation of emergency regulations on security of supply and energy prices: Council adopts measures

[43] Nakou, Georgia and Friedrich-Ebert-Stiftung. 2023. Energy Without Russia: The Case of Greece. Book. FRIEDRICH-EBERT-STIFTUNG – POLITICS FOR EUROPE. https://library.fes.de/pdf-files/bueros/budapest/20476.pdf.

course, coal. Furthermore, they seldom need refueling, which sets the foundation for energy security, even at times of increased demand.

It is important to mention that though RES projects have been amplified, in 2020, nuclear electricity exceeded the amount of electricity generating globally from wind and solar PVs combined (Figure 5).

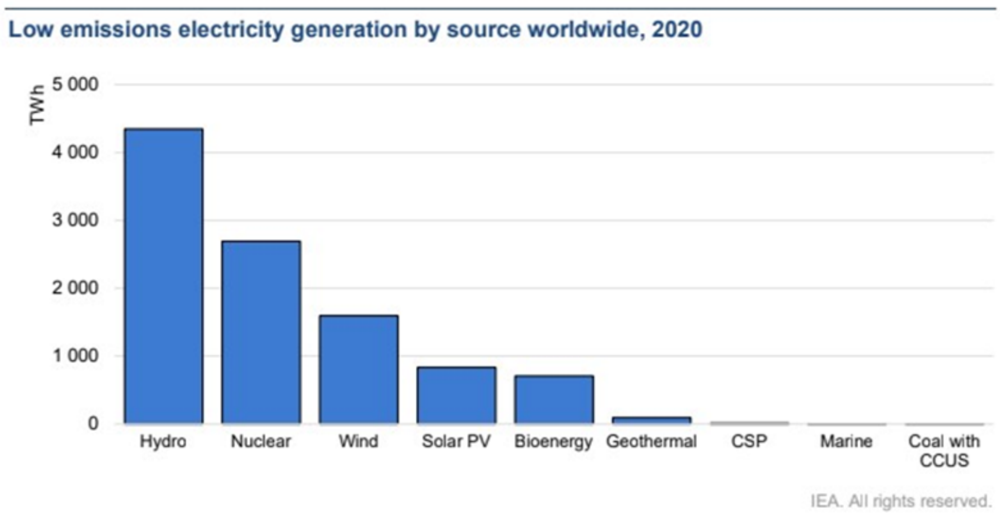


Figure 5: Depiction of how much low emissions electricity was generated by source worldwide in TW/h in 2020

Source: IEA (2021) World Energy Outlook

This contribution was made possible due to the 440 operating nuclear power reactors the combined capacity of which was 440 GWe, according to 2023 data[44].

Though this number seems high, nuclear power still represents a small share in the global energy mix, which according to September 2024 data, is only 9%[45]. Consequently, nuclear power must come a long way to become a transitory fuel during the Green transition.

[44] "Plans for New Reactors Worldwide - World Nuclear Association." n.d. Accessed June 16, 2025. https://world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.

[45] "Nuclear Power in the World Today - World Nuclear Association." n.d. Accessed June 13, 2025. https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.

However, though this increase cannot happen overnight, the signs indicate that it is inevitable. For instance, nuclear plants supplied the world with 2602 TWh of electricity in 2023 (Figure 6), an increase of 57 TWh in relation to 2022.

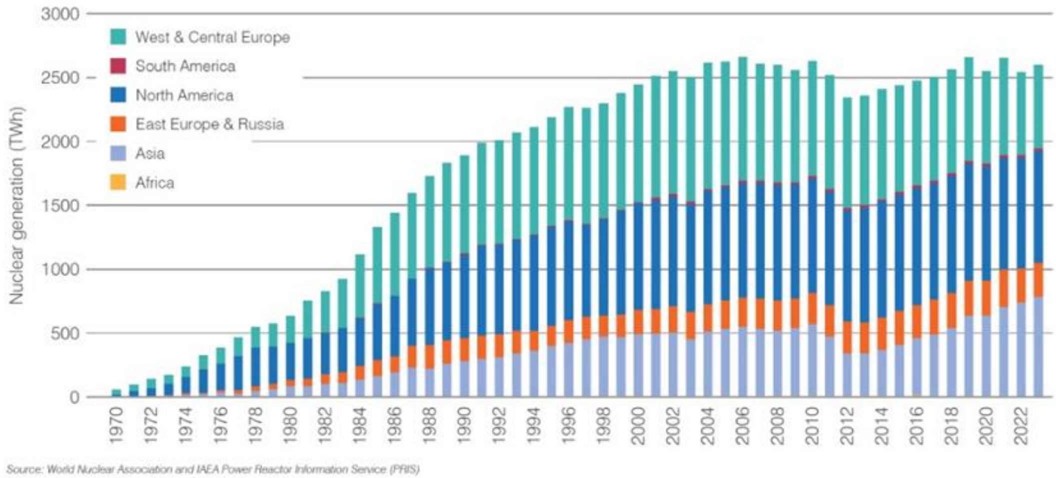


Figure 6: World's Nuclear Generation in TWh

Source: World Nuclear Association (upd. 19th August, 2024) Global Nuclear Industry Performance, https://world-nuclear.org/our-association/publications/world-nuclear-performance-report/global-nuclear-industry-performance-2023

To summarize, nuclear power is a reliable source of electricity, which allows countries flexibility of action during times of crisis and grants them energy independence given the infrequent refueling requirements of nuclear plants. By using Russia and EU as an example, especially now that the latter is scheduling a complete phase out of Moscow's energy, we could say that the European countries that have already established well-functioning nuclear fleets, will likely suffer less from the consequences of this disruption of supply, while the others will probably struggle to find alternative suppliers for gas, which was not previously sanctioned.

2.2 Nuclear Power is more reliable than RES

One of the greatest advantages of nuclear power is its reliability, since it can balance the variability of other RES's hour-to-hour or/and season-to-season power generation[46].

Solar generation by PVs for example tends, to be highly effective during daylight but is minimized at night. Furthermore, unfavorable weather conditions can hinder PVs' ability to meet demand. By taking this into consideration we can infer that PVs' susceptibility to weather conditions increases the energy net load.

The term net load refers to the remaining energy demand that must be met with the assistance of other external or internal dispatchable sources. In this regard electricity generation from PVs might as well as coincide with the total electricity demand during summer especially in countries with warmer climates, as long as advanced storage systems are created, bringing net load close to zero. However, during fall or winter, the total need for energy could not be covered solemnly by PVs especially for countries that belong to the northern polar hemisphere such as Finland and Sweden, where the sun remains absent for six months.

Similarly, wind turbines tend to be rather effective during fall, winter or spring, yet at times inadequate during summer, when the net load increases. Consequently, unless other alternatives are available at times when their effectives decrease security of supply is going to be challenged to say the least.

2.3 Environmentally friendly

It has been established that nuclear power is one of the cleanest sources of energy besides RES. This increases the former's appeal during the era of green transition, as more and more countries try to achieve net zero by 2050, as agreed in Paris Agreement. Of course, energy transition cannot be achieved through fossil fuels. For instance, it is known that coal has the worst impact

[46] "Nuclear Power Is the Most Reliable Energy Source and It's Not Even Close." n.d. Energy.Gov. Accessed June 16, 2025. https://www.energy.gov/ne/articles/nuclear-power-most-reliable-energy-source-and-its-not-even-close. Close'

on environment[47] since it releases more GHG emissions when burnt, than other fossil fuels such as natural gas[48]. What is less talked about, however, is that natural gas is responsible for releasing huge amounts of methane when burnt. Methane is a powerful GHG pollutant, responsible for around 30% of the current rise in global temperature[49]. Nonetheless aside from its foul impact on environment, methane also harms public health through ozone pollution, which has a profound effect on lung and respiratory diseases[50].

In this regard nuclear energy is considered much safer than fossil fuels from a public health perspective. The pro-nuclear movement leverages the fact that nuclear waste is not even remotely as dangerous as the toxic chemicals coming from fossil fuels. Indeed, coal and oil act as 'invisible killers'[51] and are responsible for 1 in 5 deaths worldwide[52]. In 2018 alone, fossil fuels killed 8.7 million people globally.

Consequently, given that green transition ultimately aims for net zero emissions by 2050, and not much has been done yet, a more radical step would be to further restrict the use of fossil fuels. However, such an action is simply not viable for energy intensive industries, such as steel production which require a stable and resilient supply of power to carry on their activities. In this case, nuclear power could be a very practical alternative to decarbonize the sector, while still offering the industry consistent supply of energy.

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[47] "Coal and the Environment - U.S. Energy Information Administration (EIA)." n.d. Accessed June 16, 2025. https://www.eia.gov/energyexplained/coal/coal-and-the-environment.php.

[48]"Natural Gas and the Environment - U.S. Energy Information Administration (EIA)." n.d. Accessed June 16, 2025. https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php.

[49] International Energy Agency, Global Methane Tracker 2022, Methane and climate change n.d. Accessed June 16, 2025. https://www.iea.org/reports/global-methane-tracker-2022/overview

[50] "Health Effects of Ozone Pollution | US EPA." 2025. US EPA. March 13, 2025. Accessed June 16, 2025. https://www.epa.gov/ground-level-ozone-pollution/health-effects-ozone-pollution.

[51] Milman, Oliver. 2021. "'Invisible Killer': Fossil Fuels Caused 8.7m Deaths Globally in 2018, Research Finds." The Guardian, February 9, 2021. https://www.theguardian.com/environment/2021/feb/09/fossil-fuels-pollution-deaths-research.

[52] Miller, Anna. 2024. "Fossil Fuel Air Pollution Responsible for 1 in 5 Deaths Worldwide | Harvard T.H. Chan School of Public Health." Harvard T.H. Chan School of Public Health, November 6, 2024. https://hsph.harvard.edu/climate-health-c-change/news/fossil-fuel-air-pollution-responsible-for-1-in-5-deaths-worldwide/.

2.4 Safety

After the initial shock that followed the infamous Fukushima disaster, the international community decided to take drastic action to enhance nuclear reactors' safety mechanisms. Stress tests were conducted in the US and 17 European countries to evaluate reactors' resilience to extreme natural disasters. Though the findings were mostly positive, the Western European Nuclear Regulators' Association and the European Nuclear Safety Regulators Group recommended improvements for the plants under inspection concerning containment integrity and accident mitigation strategies.

Currently western nuclear plants operate with a defence-in-depth safety approach ensuring that additional measures supplement the reactor core's natural stability. Key features include high-quality design which prevents operational errors, constant monitoring, and redundant mechanisms to control damage and confine radioactive materials. When it comes to natural disasters, plants now automatically shut down during earthquakes while tsunami protection measures, have been reinforced worldwide.

The resilience of the reactors has also magnified which allows them to withstand the impact of severe accidents, such as core melting and containment breaches.[53] Furthermore new Advanced Water Reactors, are designed with passive safety systems, which do not rely on electric power or immediate human intervention. This is particularly important in cases of a blackout.

Lastly the Severe Accident Management guidelines help operators respond to extreme events while IAEA's Unified System for Information Exchange on Incidents and Emergencies facilitates global communication during crises.

Taking all these developments into consideration, it is safe to infer that nuclear power can be considered a reliant source of electricity. However, it is important to underline that safety features must continue to evolve as technology prevails and new reactor designs come into picture.

[53] World Nuclear Association, Safety of Nuclear Power Reactors

2.5 Competitive operating costs

Though capital costs of constructing a nuclear power plant are very high, its operating costs, comprised of fuel as well as operation & maintenance costs, are rather low compared to gas or coal ones.

Specifically, the low fuel costs of nuclear plants, which include the costs of used fuel management and final waste disposal, increase the attractiveness of nuclear power. Though Uranium, has to be processed, enriched and fabricated into fuel elements and allowances must also be made for the management and disposal of radioactive used fuel, the total fuel costs of a nuclear power plant in the OECD are typically one-third to one-half of those for a coal-fired plant and between one-quarter to one-fifth of those for a gas combined-cycle plant[54].

Moreover, Uranium is a highly prolific source of energy and thus, more cost effective compared with other fossil fuels. To give an example, one kilogram of natural uranium will produce about 20,000 times more energy than coal. This also indirectly diminishes the transportation costs of electricity, as less fuel is required to be transported to produce much more energy, and thus further boosts the attractiveness of Uranium from an economic perspective.

In total the whole fuel cycle accounts for approximately 10% of the overall costs of nuclear electricity per kWh. It is important to mention though that since uranium prices have increased after Russia's invasion in Ukraine, the final contribution of fuel costs to the total costs of nuclear electricity could increase from time to time. For instance, in the first quarter of 2025, the price of Uranium was above $68 per pound globally, in comparison with a little over $50 per pound that costed during the fourth quarter of 2022 (Statista 2025).

Operation and maintenance (O&M) costs represent a much larger portion of the total operating costs, with their share being close to 70%. O&M shall be divided into 'fixed costs', and variable costs. The first incur regardless of the plant's output, while the latter differ depending on the volume of electricity production.

[54] "Economics of Nuclear Power - World Nuclear Association." n.d. Accessed May 31, 2025. https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.

Of course, the low operating costs cannot immediately make up for the extravagant initial costs of constructing a nuclear power plant. Nonetheless, in the long run they help reduce the final price of nuclear electricity for consumers, and the production costs for investors. Especially the latter has dropped substantially during the last 15 years. In US for instance, they fell from $51 per MW/h in 2012 to only $31 MW/h in 2022[55] (Figure 7).

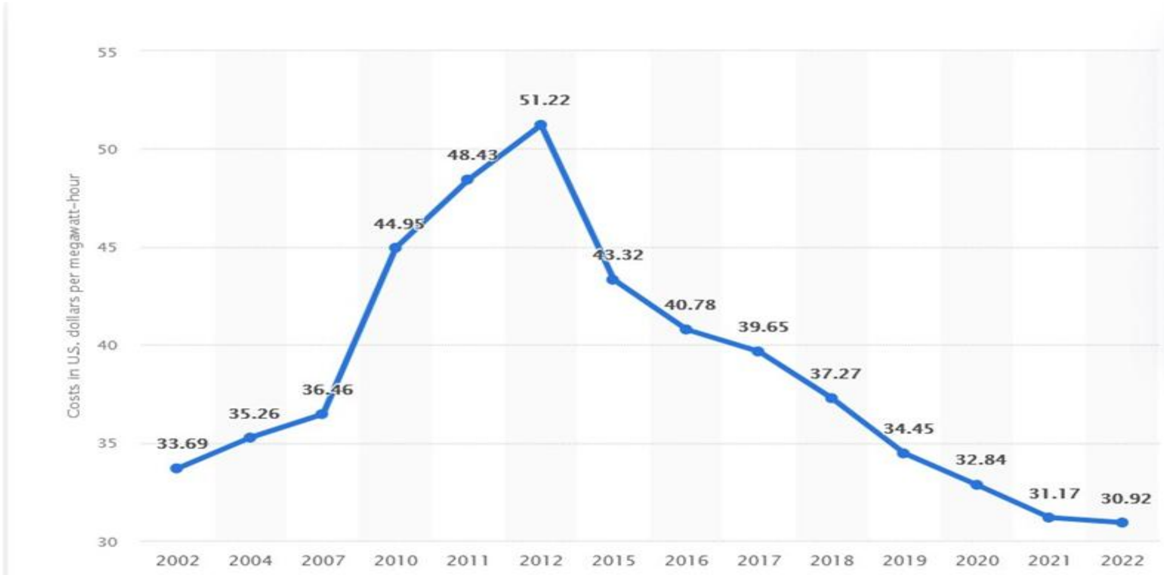

Figure 7: Production Costs for nuclear power plants in the US from 2002 to 2022

Source: Statista, https://www.statista.com/statistics/184754/cost-of-nuclear-electricity-production-in-the-us-since-2000/

2.6 Safeguards and new technologies minimize the risk of proliferation and accidents

IAEA's safeguard system under NPT has played a crucial role in ensuring that uranium, plutonium and associated plants are used by member states for civil intents and purposes only.[56] On the other hand it is no secret that some members still possess nuclear weapons. This situation

[55] Statista 2025b. "Nuclear Plants' Power Generating Costs in the U.S. 2002-2023." May 14, 2025. Accessed June 16, 2025. https://www.statista.com/statistics/184754/cost-of-nuclear-electricity-production-in-the-us-since-2000/.

[56] "Safeguards to Prevent Nuclear Proliferation - World Nuclear Association." n.d. Accessed May 17, 2025. https://world-nuclear.org/information-library/safety-and-security/non-proliferation/safeguards-to-prevent-nuclear-proliferation

is rather unfortunate and of course contradicts the Treaty's' principle concerning nuclear disarmament. However, the Nuclear Weapon Member-States of NPT are still subjected to frequent IAEA inspections and follow very specific safeguards to ensure that they do not indulge in mindless nuclear weapon production. The same applies to the five states that are not members of NPT which are India, Pakistan, Israel, South Sudan, and North Korea.

On the opposite side hundreds of nuclear facilities in 57 NNWS are also inspected regularly. These inspections aim to detect an early diversion in the use of nuclear material from what is considered a peaceful exploitation of nuclear power.

The inspection system relies on three major principles. «Material accountability» which involves monitoring all transfers and flow of materials within any nuclear facility. This encompasses the sampling and analysis of nuclear material, conducting on-site inspections, and reviewing and verifying operational records. Secondly, the principal of «Physical security» ensures that the access to nuclear material is equal to the amount required for the smooth operation of the nuclear plant. Lastly «containment and surveillance» involve the utilization of various instruments to identify unreported movement or tampering with nuclear materials, in addition to conducting on-site spot checks[57].

While this surveillance system appears sufficient, the inherent complexities of nuclear power have led several countries to establish supplementary guidelines like Euratom Safeguards, or export control systems for nuclear and nuclear related material as the ones established by the Nuclear Suppliers' Group.

In chapter 1 we have mentioned that the major disadvantage of the Non-Proliferation treaty is its voluntary feature, meaning that its terms cannot be enforced by the IAEA itself, nor can nations be coerced into signing the treaty. Nevertheless, states possess alternative means to indirectly compel other countries to adhere to the conventions of what is thought to be an appropriate way to use nuclear power. Economic sanctions may be employed to restrict or penalize objectionable conduct. This measure may be more potent if the sanctioned nation has previously relied

[57] "Safeguards to Prevent Nuclear Proliferation - World Nuclear Association." n.d. Accessed May 17, 2025. https://world-nuclear.org/information-library/safety-and-security/non-proliferation/safeguards-to-prevent-nuclear-proliferation

significantly on the sanctioning state. In this scenario, the former would be more likely to relinquish its hazardous behavior to secure financial and political euphoria.

On a completely different note, some may claim that safeguards and sanctions might guarantee compliance with the treaty's nonproliferation conditions, yet the risk of an accident is still present. Of course, as technology evolves, it should contribute to both the fight against the unwanted spread of nuclear weapons and to reducing the risk of proliferation. In this regard, the advanced nuclear reactors and fuels that have seen the light of the day could be exploited to boost the civilian use of nuclear power, even if their contribution to proliferation is still under inspection.

Almost all reactors that operate today are Water Cooled Reactors (96%). Light Water Reactors are the most common types of WCR, and they are divided into Pressurized Water Reactors (Figure 8) and Boiling Water Reactors (Figure 9) with the former contributing by far the most in nuclear electricity production.

Pressurized Water Reactors (PWRs) produce steam for the turbine in separate steam generators, while BWRs use the steam produced inside the reactor core directly in the steam turbine. All LWRs require fuel that is enriched in the fissile isotope, U-235[58].

[58] "Water Cooled Reactors." n.d. https://www.iaea.org/topics/water-cooled-reactors.

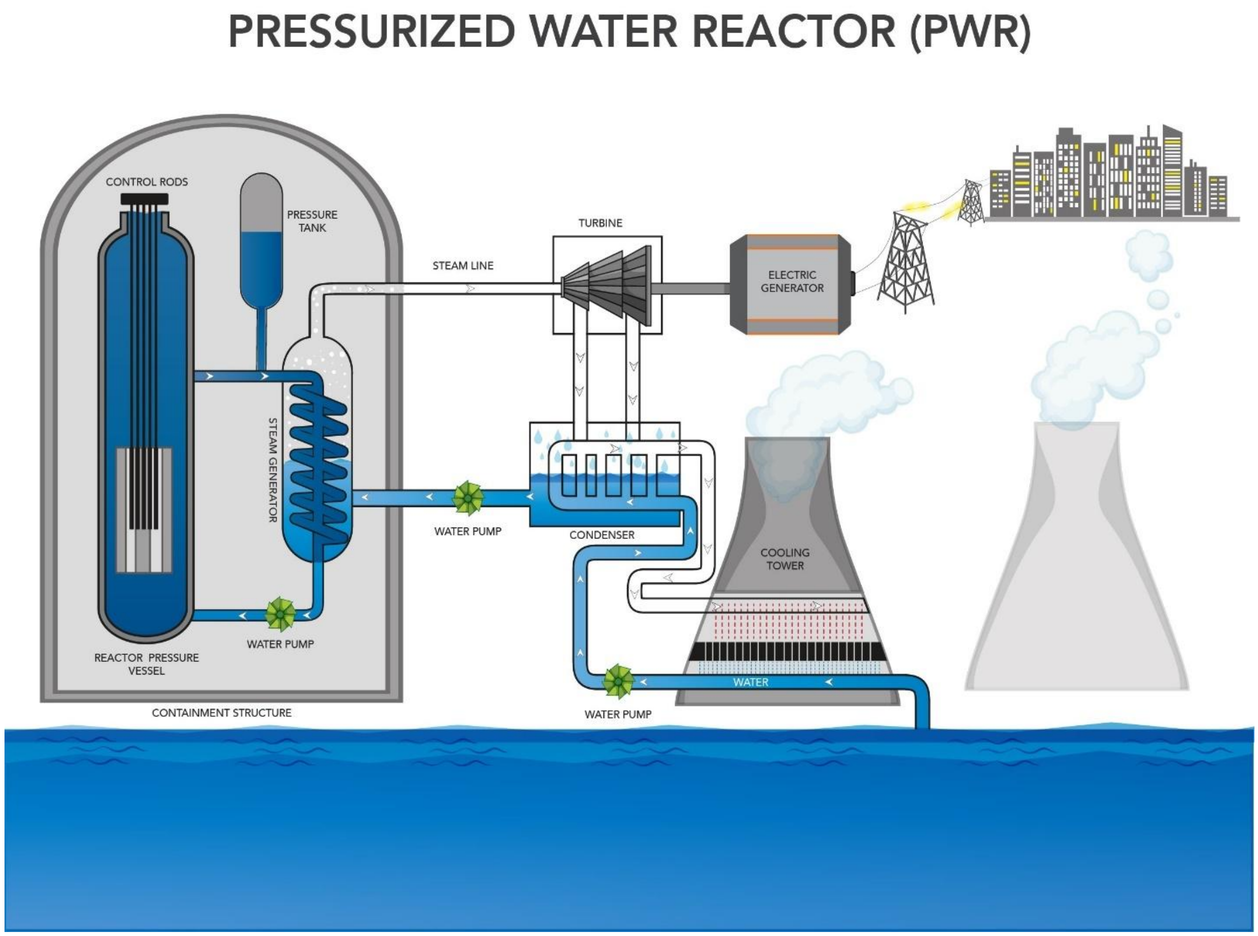

Figure 8: Depiction of a Pressurized Water Reactor

Source: US department of Energy (2019) "Infographic: How does a pressurized water reactor work?", https://www.energy.gov/ne/articles/infographic-how-does-pressurized-water-reactor-work

Boiling water reactors (Figure 9) have a single circuit in which water is held at a pressure that allows it to boil. The steam generated in the reactor is fed directly to the turbine. BWRs are primarily found in the US, Japan, Sweden and Taiwan.

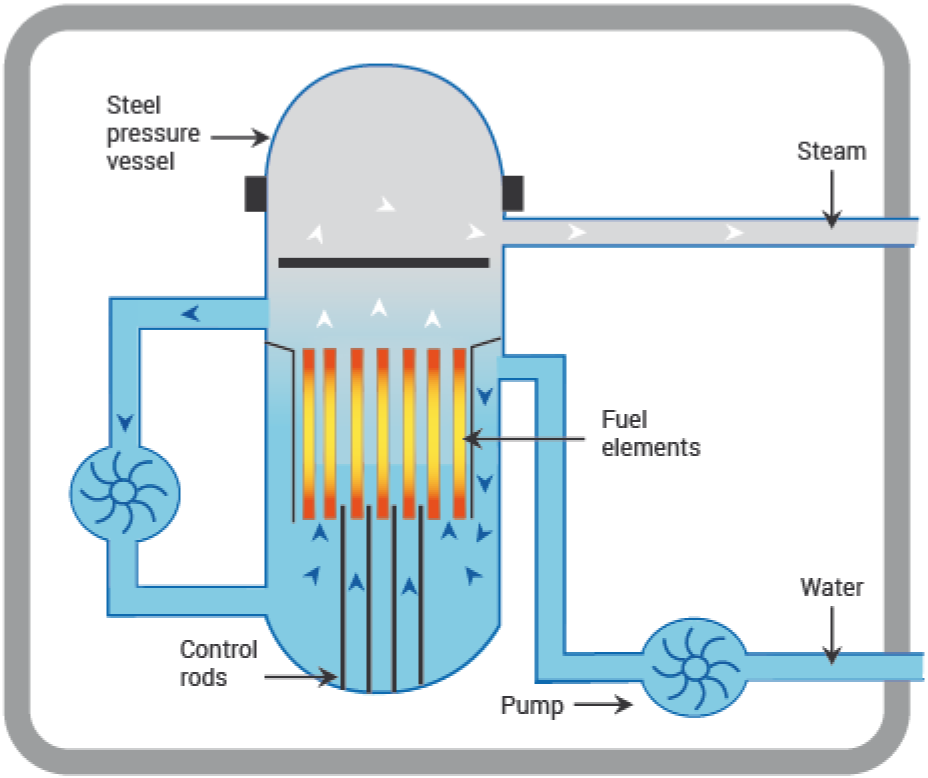

Figure 9: Depiction of a Boiling Water Reactor (BWR)

Source: World Nuclear Association (upd. 1 October 2025) "Nuclear Power Reactor"s, https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/nuclear-power-reactors

On the opposite side Heavy Water Reactors (Figure 10) use "enriched" water, the molecules of which comprise hydrogen atoms that are made up to more than 99% of deuterium, a heavier hydrogen isotope. This heavy water, used as a moderator, does not require enrichment.

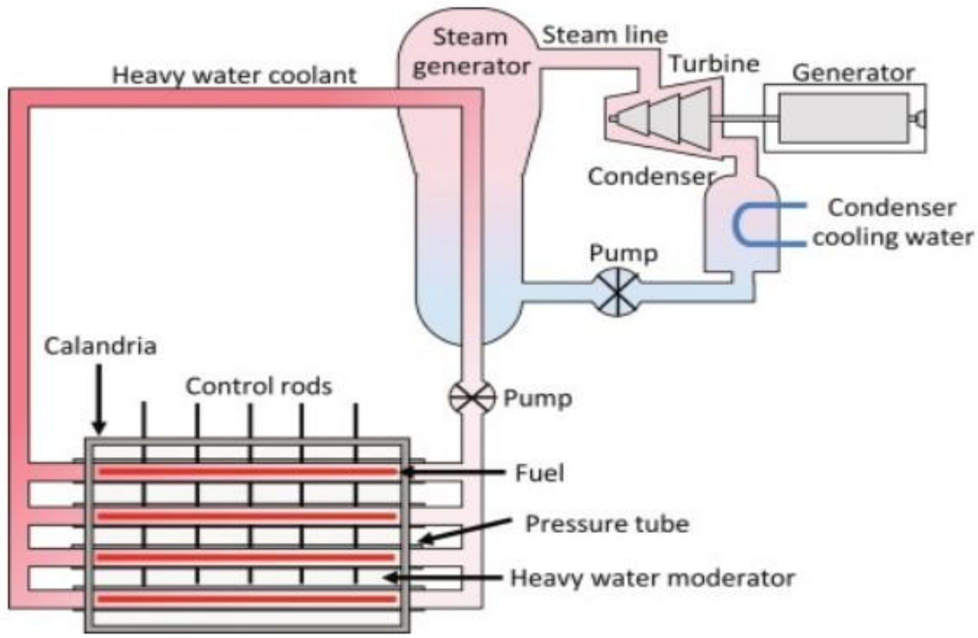

Figure 10: Depiction of a Heavy Water Reactor (HWR)

Source: Science direct "Heavy Water Reactors" https://www.sciencedirect.com/topics/engineering/heavy-water-reactors

Although these three types of WCR have served quite well the civilian purposes of civilian nuclear power and are deemed as relatively safe some advancements must be made to achieve even greater proliferation resilience and prevent large scale disasters.

Advanced Water-Cooled reactors for instance, like Small Modular Reactors and micro-reactors are designed to operate similarly to conventional ones yet on a smaller scale, which may not eliminate the risk of proliferation, but it significantly reduces the risk of large-scale disaster. Though at present there are not any SMR reactors in commercial operation, they are expected to contribute to the expansion of nuclear power in the coming years. (more on SMRs Chapter 4).

In conclusion, IAEA's safeguards have played a substantial role in reducing proliferation, yet they lack all means to prevent nuclear accidents. In this regard the development of new reactor technologies should provide a fundamental basis for a new nuclear era, of safer reactors.

2.7 New jobs

Though the creation of new jobs is hardly the first thing that comes to mind when discussing the advantages of nuclear power, it is indeed an important aspect to consider. According to IMF, investments in nuclear power produce the biggest economic multiplier effect compared to other clean energy sources. Nuclear power creates about 25% more employment per unit of electricity than wind power, while workers are paid substantially better than those working in RES projects[59]. This could boost many economies while also giving countries the opportunity to employ highly educated individuals in the energy field and thus, possibly contributing to halt the «brain drain» phenomenon.

To elaborate, the great majority of these vacancies will be created during the planning and construction stages of nuclear plants, when thousands of people will be involved. Moreover, somewhere between 400-700 'full-time equivalents are required to ensure the smooth operation of a nuclear reactor including those employed in O&M (Operation and Maintenance) and offsite maintenance workers. [60] Finally, during the decommissioning of a nuclear power plant approximately 3,000 people will be occupied in a span of decades.

It is important to note that these numbers may vary, depending on the country or region. In the US for instance the nuclear energy sector directly employs more than 70,000 people in high-quality, long-term jobs and 250,000 in total if we add secondary ones. A single plant can employ 400-700 O&M workers but 9,000 during construction. Additionally, the salaries provided are 50% higher than those of other generation sources[61].

[59] Batini, Nicoletta, Mario Di Serio, Matteo Fragetta, Giovanni Melina, Anthony Waldron, Prakash Loungani, and Chris Papageorgiou. 2021. "Building Back Better: How Big Are Green Spending Multipliers?"

[60] Emsley, Ian and World Nuclear Association. 2020. "Employment in the Nuclear and Wind Electricity Generating Sectors." https://world-nuclear.org/images/articles/Employment-in-Nuclear-Report-Final.pdf.

[61] 2024 U.S. Energy & Employment Jobs Report (USEER)

Concerning European nuclear industry, it sustained more 1.1 million jobs in 2019 with 350.000 being directly connected to nuclear power, according to a study by Deloitte.[62] When it comes to Asia, China National Nuclear Corporation counted 180,000 employees in 2023 for instance, while around 42,000 people worldwide worked for China General Nuclear Power group. In South Korea the number of people that worked in nuclear field was close to 35,000 in 2021. Kazakhstan, on the other hand estimates that its first nuclear power plant will create 2,000 permanent jobs with an additional 10,000 workers involved during its construction[63].

To conclude, it is evident that nuclear power has the potential to boost domestic GDP per capita by providing a significant number of well-paid jobs, especially in western countries such as USA and EU, where almost one and a half million people are directly or indirectly occupied in the nuclear sector. This situation could simultaneously provide an incentive for highly educated individuals in the field of energy to remain in their countries of origin rather than seeking job opportunities in other countries.

2.8 Conclusions

Nuclear power not only offers important financial and economic benefits for the countries exploiting it but is also one of the cleanest and safest forms of energy for the environment. The relatively infrequent refueling requirements of the plants allow countries some flexibility and provide them with security of supply and energy independence in times of crisis. Also, the low operating costs of nuclear plants impact the cost of nuclear power in the long run, leading to a significant reduction of nuclear prices per kilowatt. This increases the attractiveness of the sector for final consumers, but also for investors who favor long-term over short-term gains.

[62] European Atomic Forum, Deloitte, Sorin Elisei, Yves Desbazeille, and Jessica Johnson. 2019. “Investing in Low-carbon Nuclear Generates Jobs and Economic Growth in Europe.” Press-release. European Atomic Forum. April 25, 2019. https://www.foratom.org.

[63] Pokidayev, Dmitry. 2025. “Kazakhstan to Train Workforce for Future Nuclear Power Plants - the Times of Central Asia.” The Times of Central Asia (blog). January 8, 2025. https://timesca.com/kazakhstan-to-train-workforce-for-future-nuclear-power-plants/.

Furthermore, nuclear power could boost domestic economies, by providing high quality jobs with respectable salaries to highly expertise individuals, to prevent them from seeking occupation in other countries.

On the other hand, IAEA safeguards promote the goal of non-proliferation while advanced safety systems increase the inherent safety characteristics of the reactors by reducing the chances of a large-scale disaster such as the cases of Fukushima and Chernobyl. In this regard new reactor designs, including SMRs, are considered less dangerous due to their small capacity.

However, it is important to note that nuclear power plants still presents some negative qualities, especially concerning their capital costs, waste management issues, long construction time and fears regarding proliferation due to the fears regarding new advances reactors that allow uranium enrichment up to 20%, unlike 5% which is the common now.

3. CHAPTER THREE: DISADVANTAGES OF NUCLEAR POWER

3.1 Huge capital costs

The high capital costs associated with a new nuclear power plant often prohibit countries from expanding the domestic use of nuclear power. These costs are incurred prior to and during the construction of the plant, as well as during the design and licensing process. Particularly, the often-overlooked licensing costs hold significant importance. After all, regulatory fees typically amount to $60 million per reactor, while vendors' costs are $180–$240 million per design.

Aside from licensing costs, there are as we mentioned other types of capital costs. Overnight costs are financing charges accrued during the construction period. They mostly include engineering, procurement and construction (EPC) costs and other unplanned expenses. According to the 2020 edition of the Projected Costs of Generating Electricity joint report by the IEA and the NEA, the overnight costs for nuclear plants varied significantly worldwide, ranging from $2,157 per kWe in South Korea to $6,920 per kWe in Slovakia[64].

Construction or investment costs refer to the total capital costs, encompassing the overnight costs that we mentioned prior. This metric is valuable for assessing the overall cost of constructing a nuclear plant and understanding the impact of any delays. Generally, construction costs of nuclear plants are way higher than coal- or gas-fired ones, primarily due to the unique features and safety systems that the former require. These differences can be explained by the dissimilar labour cost and level of expertise in each country, as well as the economies of scale achieved when constructing a large scale of nuclear units.

It is important to mention that to directly compete with RES, the construction costs of nuclear power plants need to be reduced to $2,000 per kilowatt (the 2020 value) or less. This is exceptionally difficult for Western countries such as the US and Europe, where construction

[64] "Economics of Nuclear Power - World Nuclear Association." n.d. https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.

costs range from $6,000 to $12,000 per kW for a 1,000 MW plant [65]. On the other hand, in East Asia they vary from $2,500 to $4,000 per kW, making them way more cost-efficient and competitive. In any case, however, due to the rise of global inflation, the construction costs are expected to increase worldwide, including where they are relatively lower.

At last, the financing cost refers to the interest charged on debt, which is influenced by the construction period and the applicable interest rate. Consequently, the costs associated with nuclear power projects increase relatively quickly as the discount rate rises.

In short, nuclear plants' high capital costs, including licensing fees, overnight, construction, and financing costs are significant and often prevent countries from expanding the domestic use of nuclear power. Therefore, to compete with other forms of renewable energy, they need to be reduced.

3.2 Long Construction Times

Generally, it takes approximately 10 years for nuclear power reactors to be connected to the grid from the day their construction begins, according to data from the 2014-2023 period[66]. There are several reasons behind these delays, including technical issues, shortages of qualified staff, supply chain disruptions, and strict regulations, with the longest delays occurring in the US, where they can extend for decades[67].

Europe is not immune to such delays. For instance, EDF confirmed that due to technical difficulties, the Hinkley Point C nuclear plant in Somerset, England, will not be ready for

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[65] Amy, Jeff. 2024. "US Energy Secretary Calls for More Nuclear Power While Celebrating $35 Billion Georgia Reactors | AP News." AP News. August 15, 2024. Accessed May 31, 2025. https://apnews.com/article/georgia-nuclear-plant-energy-secretary-granholm-05a6e2444a8b5a9e9c7c61b111b87192.

[66] "Mean Construction Time for Global Nuclear Reactors Completed Between 2014 and 2023, by Country and Number of Units." 2024. Statista. October 7, 2024. Accessed May 31, 2025. https://www.statista.com/statistics/1328102/construction-time-for-nuclear-reactors-worldwide/.

[67] Tauschinski, Jana, and Rachel Millard. 2024. "Why Are Nuclear Power Projects so Challenging?" Financial Times, February 1, 2024. https://www.ft.com/content/6d371375-b7be-4228-a3d5-2ad74f91454a.

commercial operation until at least 2029. Additionally, Poland's first nuclear power reactor, with a capacity of 1-1.6 GW, was initially scheduled for commissioning in 2033. However, Wojciech Wrochna, the country's Secretary of State at the Ministry of Industry, announced in December 2024 that a three-year delay is now expected according to a revised schedule. Furthermore, the Flamanville 3 EPR nuclear reactor, France's most powerful to date, finally began supplying consumers with electricity in 2024 after a 12-year delay and a four-fold increase in the project's overall cost[68].

On the other hand, construction times are shorter in Asia. In South Korea, for instance, Shin Kori Units 3 & 4 took only 5.5 years to begin their commercial operation. Similarly in China the construction of Fuqing Unit 5 began in 2015 only for the reactor to begin its operation in 2020.

Long construction times also negatively impact the internal rate of return. In other words, the projects' profitability decreases the more the date of their supposed commercial operation extends. This is a major obstacle for the expansion of nuclear projects, especially in Western countries, and heavily discourages investors. Therefore, failure to take immediate action could result in a "strangulation" of capital for nuclear investments.

3.3 Nuclear Waste and Pollution

The proper management of high-level radioactive waste is a critical issue in the nuclear power sector. High-level waste encompasses used nuclear fuel from reactors and waste produced from the reprocessing of spent nuclear fuel.[69] The latter is particularly important, as it is, in some countries, the greatest source of high-level radioactive waste, which can remain dangerous for up to 1 million years[70].

[68] NEWS WIRES. 2024. "France's Most Powerful Nuclear Reactor Comes on Stream After 12-year Delay." France 24, December 21, 2024. https://www.france24.com/en/live-news/20241221-france-s-most-powerful-nuclear-reactor-finally-comes-on-stream.

[69] "Radioactive Waste | US EPA." 2025. US EPA. January 27, 2025. Accessed May 31, 2025. https://www.epa.gov/radtown/radioactive-waste.

[70] Donald N. Zillman Siting Nuclear Waste Repositories p. 336

Current waste management methods include treatment, storage, and disposal of radioactive material. Treatment methods aim to reduce the volume and the radioactivity of waste, while storage technics provide a temporary solution before the waste's final disposal.

There are two commonly accepted disposal options for radioactive waste. The first is near-surface disposal, which involves disposing of low-level and most intermediate-level radioactive waste at or just below ground level. The second option is deep geological disposal, which is used for specific intermediate and all high-level radioactive waste. This method involves burying the waste at depths ranging from 250 meters to 1,000 meters for mined repositories or from 2,000 meters to 5,000 meters for boreholes.[71]

Deep geological disposal is deemed the safest form of radioactive waste disposal since it addresses the problem of high-level waste, as we saw. It is therefore used in most countries, including Australia, Canada, France, Japan, Switzerland, the UK, and the USA. However, a very severe earthquake could compromise its integrity, as it could destroy these underground sites, and lead to the uncontrolled release of radioactive material and groundwater contamination.

This could have a pretty negative effect on both the environment and human health. It is therefore unsurprising that the public's view regarding the matter is still negative. Indeed, safety measures must be evaluated, and more capital should be invested in innovative projects concerning the disposal and other means of radioactive waste management. Unless this is achieved, nuclear waste will continue to raise suspicion and hinder the potential spread of the use of nuclear power.

3.4 Nuclear proliferation

[71] "Storage and Disposal of Radioactive Waste - World Nuclear Association." n.d. Accessed June 1, 2025. https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste

Though notable effort has been made to minimize the risk of proliferation, it obviously cannot be eliminated. As the use of nuclear power expands worldwide, its exploitation for non-civilian purposes becomes more and more possible.

There are several reasons why states aim to acquire nuclear weapons, with safety being the most important one. North Korea, for example, withdrew from the NPT in 2003, stating that the treaty failed to comply with its safety concerns. Furthermore, India and Pakistan, both of which are NWS, have also never been members of the treaty. Given their tumultuous relationship, neither country appears willing to disarm and join the NPT, as each fears a nuclear attack from the other. After all, the latest brief yet alarming turbulence in the region of Kashmir has likely reinforced their mutual suspicion against each other.

Similarly, Israel, which has never been a member of the NPT, is unlikely to join the treaty now that it is engaged in conflict with Hamas. Additionally, its relations with Iran—its sworn enemy for many years and a supporter of Hamas and Hezbollah—are on the brink of war. Meanwhile, the Washington-Tehran negotiations aimed at establishing a new, safer Iranian nuclear deal have not yielded significant progress so far, heightening concerns in Tel Aviv.

On the other hand, even if all non-members of the NPT decide to join the treaty, the risk of nuclear proliferation would not suddenly vanish. This is due to certain inherent disadvantages associated with the treaty and the IAEA's safeguards. For instance, paragraph 14 of the NPT permits fissile material intended for non-explosive military purposes, such as naval propulsion, to be exempt from inspections and monitoring by the IAEA. This exemption is concerning as it creates a precedent that countries might exploit to conceal highly enriched uranium or plutonium.

This concern is particularly relevant when considering the new advanced reactors. High-Assay Low-Enriched Uranium reactors, for example, consist of uranium enriched between 5% and 20% uranium-235, exceeding the capacity of current conventional reactors. While this characteristic can enhance a reactor's efficiency, it simultaneously increases the risk of proliferation.

In other words, there are safety loopholes in the current legislative framework that states could exploit and therefore conceal nuclear materials or facilities. To address this issue, the IAEA has established the Additional Protocol, as we saw in chapter 1, that can be voluntarily incorporated into an IAEA safeguards agreement. In September 2024, 142 member states plus Euratom have concluded Additional Protocols in their safeguards, that are now in force[72].

Besides the IAEA, other members of the international community have taken steps to strengthen the nonproliferation rules. On 24 January 2024, the Commission published a White Paper on Export Controls in the context of growing geopolitical tensions[73]. Furthermore, bilateral agreements between a state and a public utility often provide a stricter regulatory framework that further discourages displeasing conduct between the two trading parties.

However, we must acknowledge the need for further action. After all, the current regulatory framework for nuclear power was created to address the issues of more traditional reactors and is therefore becoming increasingly old-fashioned.

Taking all this information into consideration, while the NPT and IAEA safeguards have significantly contributed to establishing a strong legal framework for appropriate behavior regarding nuclear power, more should be done to reduce the risk of proliferation and to tackle the challenges posed by new reactor technologies.

3.5 Accidents

Despite precautions and safety systems, the risk of a nuclear accident cannot be eliminated. After all, natural phenomena, like earthquakes and tsunamis, occur one way or another and could, on some rare occasions, trigger disasters, even if all safety protocols are implemented.

Though the general impact of nuclear accidents has proven to be less terrifying than we once feared they remain sources of socio-economic and psychological suffering for the inhabitants of the affected area. People who are affected by the accident or have been forced to evacuate

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[72] "Additional Protocol." IAEA n.d. Accessed June 2, 2025. https://www.iaea.org/topics/additional-protocol.

[73] "Exporting Dual-use Items." 2025. Trade and Economic Security. April 16, 2025. Accessed May 23, 2025. https://policy.trade.ec.europa.eu/help-exporters-and-importers/exporting-dual-use-items_en.

because of it often face stigmatization. Marginalization has been linked with alcoholism, depression, anxiety, bullying, and suicides[74].

Accidents could also lead to health issues. Acute Radiation Syndrome, which initially causes nausea, vomiting, fever, hair loss, or loss of appetite, develops within an hour of exposure to large doses of ionizing radiation that occur after a nuclear accident and can last for several months[75]. Leukaemia and thyroid cancers could also occur in the long run[76]. For instance, after the Chernobyl disaster approximately 5.000 people developed thyroid cancer due to radiation exposure.

Concerning the environmental impact of nuclear accidents, toxic radioactive leaks can pollute both soil and the bodies of water in the proximity of the plant. This is harmful both for fisheries and other animals, while it also impacts agriculture. Combined with a potential leak of radioactive material from a deep geological disposal site, the results could be quite alarming.

Geopolitical factors have also raised concerns about the likelihood of a new nuclear accident occurring. Specifically, following Russia's invasion of Ukraine in February 2022, and particularly after Moscow took control of the Zaporizhzhian nuclear power plant (Figure 11)—the largest in Europe—on March 4, 2022, IAEA has been consistently worried about the facility. Director General Rafael Grossi has made multiple visits to inspect its condition, as Moscow and Kyiv frequently accuse each other of targeting the area around the plant, which often results in blackouts. In the IAEA's 2024 report, Grossi noted that: *«Amid the significant challenges and risks to nuclear safety and security, we are steadfast in our mission to assess the situation and keep the international community informed.*[77]»

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[74] World Nuclear Association, what are the effects of nuclear accidents?

[75] "Acute Radiation Syndrome." 2024. Radiation Emergencies. April 10, 2024. Accessed June 16, 2025. https://www.cdc.gov/radiation-emergencies/signs-symptoms/acute-radiation-syndrome.html.

[76] Donnelly, EH; Nemhauser, JB; Smith, JM; Kazzi, ZN; Farfán, EB; Chang, AS; Naeem, SF (June 2010). "Acute radiation syndrome: assessment and management". Southern Medical Journal. 103 (6): 541–546

[77] "IAEA Report Highlights Two Years of Efforts to Prevent an Accident at Ukraine's Zaporizhzhya Nuclear Power Plant." IAEA, September 4, 2024. https://www.iaea.org/newscenter/pressreleases/iaea-report-highlights-two-years-of-efforts-to-prevent-an-accident-at-ukraines-zaporizhzhya-nuclear-power-plant.

Figure 11: Photo of the Zaporizhian Nuclear Power Plant

Source: Maryam Zakir-Hussain (8 August 2022), "Russian troops 'firing -missiles from Europe's largest nuclear plant' amid warning of Chernobyl-style disaster", independent, https://www.independent.co.uk/news/world/europe/russia-ukraine-nuclear-chernobyl-b2140190.html

To summarize, one could say that, though nuclear accidents are considered «black swan events», they can still happen due to natural and geopolitical factors. Moreover, despite their impact being smaller than what was previously thought, social and health factors linked to large-scale disasters reduce public acceptance and discourage many countries from establishing nuclear plants. This, of course, is rather unfortunate for the further expansion of nuclear power.

3.6 Conclusions

The steep initial costs of nuclear power plants, which are divided into financing, construction, and overnight costs, frequently prohibit countries from expanding or initiating the use of nuclear power domestically. Capital costs also vary per country due to factors such as economies of scale, different labour costs, and levels of expertise. To contend directly with renewable energy sources (RES), nuclear power plants must reduce their construction costs to $2,000 or less (2020 value), something that is more difficult to achieve in Western countries.

The prolonged construction periods are another important drawback of nuclear power facilities, as they rarely commence operations according to the established schedule. Technical issues, shortages of qualified staff, and supply chain disruptions are among the factors that contribute to these delays. The United States exhibits the longest delays in nuclear construction, while China and South Korea construct nuclear reactors the fastest.

The proper management of high-level radioactive waste is also a critical issue in the nuclear sector, as it can remain dangerous for hundreds of thousands of years. Current waste management methods include treatment, storage, and disposal. Two commonly accepted disposal options are near-surface disposal and deep geological disposal. Deep geological disposal is considered the safest, but severe earthquakes could compromise its integrity, leading to uncontrolled release of radioactive material and groundwater contamination. To address this issue, safety measures and investment in innovative projects are needed.

Another major problem that could occur if nuclear power were to be used universally is the risk of proliferation of nuclear weapons, which is probably one of the most frightening developments regarding nuclear power. This is mainly due to the NPT's inherent flaws and the IAEA's safeguards, as well as the fact that some countries are not NPT members. To guarantee that states do not hide any nuclear material or activities, the IAEA has implemented an Additional Protocol. More than 140 states had signed safeguards agreements with the IAEA, which included an Additional Protocol, up to 2024. Other examples of initiatives taken at the regional and international level to enhance the effectiveness of non-proliferation safeguards are the European Commission's White Paper on Export Controls and other bilateral agreements between states and public utilities.

At last, concerning nuclear accidents, we shall stress that, despite increased safety measures, they could still be incurred by many factors, including natural phenomena that cannot always be predicted. Although nuclear catastrophes are less negative than we once thought, they can cause socio-economic, psychological, and health problems for affected individuals while also harming the environment. Simultaneously, geopolitical instability, specifically Russia's invasion of

Ukraine and Moscow's takeover of the Zaporizhzhia nuclear power plant, poses a significant threat. In conclusion, nuclear accidents are classified as "black swan events" because of the natural and geopolitical factors, as well as the social and health factors associated with large-scale disasters, which reduce public acceptance and discourage numerous countries from constructing nuclear facilities.

4. CHAPTER FOUR: SMALL MODULAR REACTORS (SMRs)

4.1 What are SMRs?

Small modular reactors (Figure 12) are advanced nuclear reactors that have a capacity of generating up to 300 MW(e) of electricity per unit, about one-third of the generating capacity of traditional nuclear power reactors[78]. They can use a range of coolants, including light water, liquid metal, or molten salt[79].

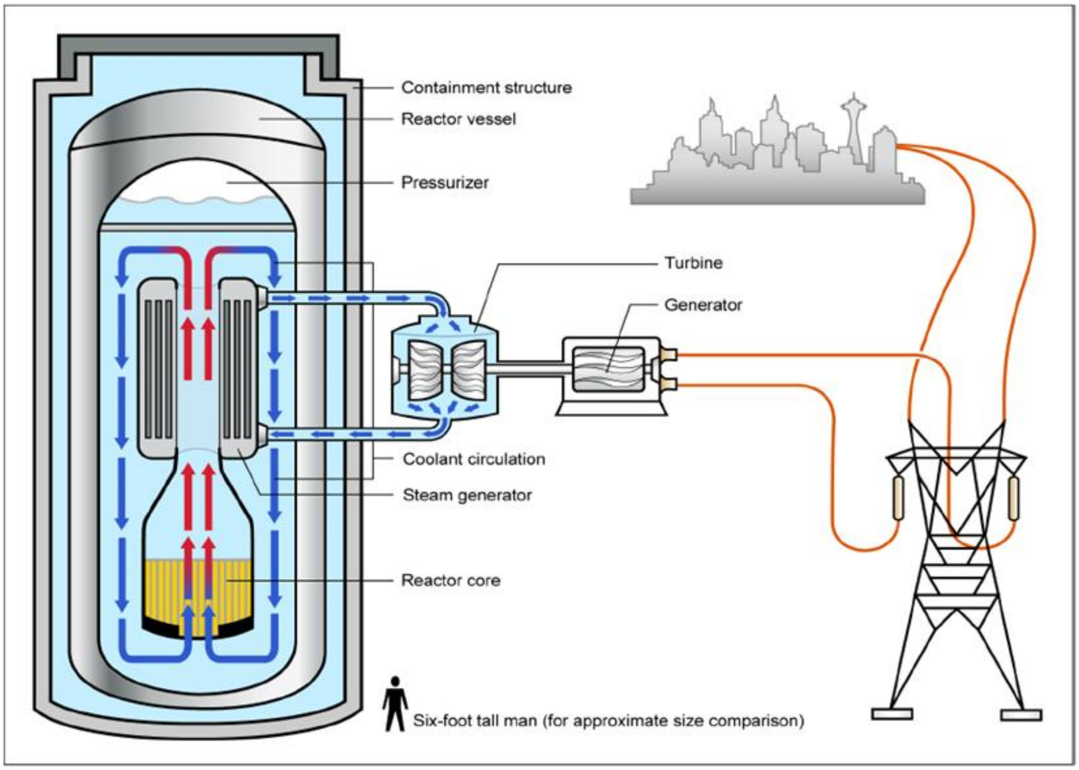
Even though more than 80 SMR projects are currently under development in 19 states[80], only China and Russia have successfully built operational reactors of this kind[81]. Russia's first floating nuclear power plant, Akademik Lomonosov, began operating commercially in 2020, producing energy from two 35 MW(e) SMRs. China's pebble-bed modular high-temperature gas-cooled reactor HTR-PM was connected to the grid in 2021.

[78] Liou, Joanne. 2023. "What Are Small Modular Reactors (SMRs)?" IAEA, September 14, 2023. https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.

[79] European Commission, Small Modular Reactors explained

[80] "IAEA Ups Support for SMRs - Nuclear Engineering International." Nuclear Engineering International. February 23, 2024. Accessed June 16, 2025. https://www.neimagazine.com/advanced-reactorsfusion/iaea-ups-support-for-smrs-10528638/?cf-view.

[81] Kimball, Spencer, and Gabriel Cortés. 2024. "Small Nuclear Reactors Could Power the Future — the Challenge Is Building the First One in the U.S." CNBC. September 7, 2024. Accessed June 16, 2025. https://www.cnbc.com/2024/09/07/how-small-modular-reactors-could-expand-nuclear-power-in-the-us.html.



Source: GAO, based on Department of Energy documentation. | GAO-15-652

Figure 12: Depiction of a Small Nuclear Reactor (SMR)

Source: GAO, based on Department of Energy Documentation, GAO – 15-652

4.2 Advantages of SMRs

4.2.1 Inherent safety characteristics

Small Modular Reactors are, by default, safer than conventional reactors. This is probably one of their greatest advantages and could contribute to shifting the negative public outlook on nuclear power. Particularly, SMRs' lower power generation capacity enhances the effectiveness of their passive safety systems[82]. These systems are of paramount importance because they do not

[82] Fraser, Peter, Brent Wanner, Keith Everhart, Antoine Herzog, and International Energy Agency. 2022. "Nuclear Power and Secure Energy Transitions" Interview by OECD Nuclear Energy Agency, International Atomic Energy Agency, World Nuclear Association, Terrapower, Nuward, Ontario Power Generation, Nuclearelectrica, et al. Directed by Keisuke Sadamori. International Energy Agency. https://iea.blob.core.windows.net/assets/016228e1-42bd-4ca7-bad9-a227c4a40b04/

require human intervention to operate in cases of emergency. Therefore, it is much easier to avoid accidents.

Additionally, some of these systems have the capacity to limit the radioactivity released into the environment, provided that an accident eventually occurs. This is a very significant feature, as it solves the complicated problem of finding appropriate sites to build nuclear power plants. After all the releases of radioactive material that resulted from the Three Mile Island accident, Chernobyl, and the Fukushima Daiichi disaster forced hundreds of thousands of people into displacement. However, an evacuation will not be required if the impact of a potential accident is curbed to a substantially smaller region, allowing SMR plants to be constructed even near settlements.

4.2.2 SMRs require smaller investments

It is only fair that smaller reactors require smaller investments. However, SMRs possess some added features that further lower their construction cost in comparison with conventional plants.

To begin with, SMR's design is far more simplistic. Due to their passive safety systems, they lack components that would complicate their use, such as valves, pumps, and cables. Moreover, the cost of creating an SMR can be lower compared to that of conventional reactors since the former can be produced in series. This unlocks the field of mass production, which enables manufacturers to benefit from economies of scale

Additionally, they are often designed in factories and then transported to the location of choice, which significantly diminishes installation costs, a major deterrent factor against further investments in nuclear energy.

Finally, unlike larger nuclear power plants, SMRs require less time to construct. This is highly beneficial for investors, as the sooner the project is done, the lower the risk of abandoning it before it is complete due to unexpected expenses. However, an increase in the number of investors could lead to more capital, thereby facilitating more projects and creating more jobs.

All these added factors make SMR more financially viable.

4.2.3 Infrequent refueling

In Chapter 2, we discussed that conventional nuclear plants require infrequent refueling. However, Small Modular Reactors have even less frequent refueling needs. On average, while larger plants require refueling every 1 to 2 years, SMR plants typically need refueling only every 3 to 7. Some SMRs are even designed to operate for up to 30 years without any refueling, depending on their size, as smaller reactors require less fuel to function.

This feature helps diminish the operational costs of nuclear plants. After all, despite still representing a small fraction of the plants' total operating expenses, fuel costs could rise, given that uranium prices rise as well. An increase in the operating cost of a nuclear plant could negatively impact both investors and consumers, as it could also result in an increase in the price of electricity for the final customers. Consequently, Small Modular Reactor projects are more likely to be perceived positively by both sides of the market.

4.2.4 More attractive to countries with smaller grids

SMRs could play a pivotal role in ensuring the security of energy supply in regions with smaller grids. For instance, microreactors, designed to generate electricity up to 10 MW(e), could serve as a backup power supply in emergency situations or replace generators that are often fueled by diesel. Therefore, Small Modular Reactors could supply households and industries with a reliable and, of course, clean form of energy at all times.

4.2.5 Efficiency and Flexibility

Countries can use SMRs to enhance the effectiveness of renewable energy by putting them into operation when windless or rainy days affect the performance of photovoltaics or windmills. This could present an interesting choice for countries that are skeptical towards nuclear power but would still like to use it moderately as a substitute for RES.

Furthermore, it is important to note that, despite their size, SMRs are designed to serve similar purposes to larger nuclear plants. Therefore, they will be able to produce hydrogen, heat, or even desalinate water, though at a smaller scale. This broad range of usages, combined with the lower cost of SMRs compared to larger reactors, could further increase their appeal, leading to more investments.

4.3 Disadvantages of SMRs

4.3.1 Still high costs and long construction times

The cost of constructing a Small Modular Reactor (SMR) remains significantly higher than the costs associated with other renewable energy projects.

When it comes to ensuring the security of supply, the inherent drawbacks of photovoltaics and windmills are placing them at a disadvantageous position against nuclear power. However, their short construction times, accompanied by the fact that they require far less expertise to build, lower the risk for investors, thus increasing the attractiveness of RES projects, even if their generation capacity fluctuates.

Furthermore, unlike nuclear power, renewable energy has been well established worldwide for quite some time and is generally viewed positively. Over the years, numerous suppliers have emerged, creating a competitive and lucrative market. In contrast, the nuclear market is smaller and heavily regulated. These factors discourage further investments in the nuclear sector, including SMRs, thus limiting its potential for expansion.

Finally, it is essential to include a plethora of specific provisions for Small Modular Reactors in the current regulatory framework regarding nuclear power. Legal obstacles can lead to further delays in the completion of the projects, which are already taking longer than anticipated, even though they are still quicker than the construction of conventional plants.

Under these circumstances, we can infer that though SMR technology sounds promising, it still has a long way to go to play an important role in Green Transition for at least 10 years from now[83].

4.3.2 Difficult refueling

Indeed, SMRs' rare need for refueling is a plus compared to their larger counterparts. Nonetheless, the procedure itself, from finding a supplier to closing a cost-effective deal, is truly burdensome in this case.

We have seen that the nuclear market is underdeveloped. To make matters worse, some Small Modular Reactor designs rely on innovative fuels that are either hard to find or not commercially available yet. This limits the number of potential fuel suppliers, meaning that the few existing ones will enjoy a great market share once all projects finish. In other words, even if a supplier is found, it will be extremely hard to negotiate a good price.

Additionally, proliferation concerns have made selling and buying dual items difficult, which prohibits potential suppliers from entering the market. This predicament can further hinder the expansion of the sellers' network, thus maintaining the refueling-related problems.

4.3.3 Proliferation

Even though SMRs are not ready to substantially contribute to the Green Transition at the moment, it is possible that they will do so after 15–20 years. However, much like in the cases of larger reactors, an expansion of SMRs could increase the risk of nuclear proliferation. After all,

[83] "Small Modular Reactors: Still Too Expensive, Too Slow and Too Risky | IEEFA." n.d. Accessed June 16, 2025. https://ieefa.org/resources/small-modular-reactors-still-too-expensive-too-slow-and-too-risky.

despite their flaws, they still present a more viable alternative for countries that want to invest or reinvest in nuclear energy but lack the financial means to construct larger reactors. Moreover, if the SMR projects currently under development prove to be successful, more investments will occur. This, once again, brings the outdated regulatory framework to the forefront of this analysis.

We mentioned that by focusing on conventional nuclear power reactors, the current safeguards often fail to encapsulate SMRs' peculiarities. This presents an excellent opportunity for countries to cap ambiguous technology and items. After all, despite the nuclear sector being heavily regulated, there will always be room for states to commit wrongdoings, especially if the framework is old or national security is involved. The latter is of particular interest, as dangerous behavior is expected during times of global turmoil, like the ones we live in.

In March 2015, the SMR Regulators' Forum emerged to tackle this issue. Its purpose is to prompt countries and other parties to exchange nuclear-related knowledge and experience. By deepening their understanding of the matter, the participants could contribute to upgrading the outdated legal framework concerning nuclear power. Simultaneously, the IAEA is evaluating the extent to which innovative technologies can incorporate existing safety standards.

However, as digital transformation prevails, new technologies will often appear and create new opportunities for proliferation. In this regard, the IAEA and decision-makers worldwide should either constantly reevaluate their safeguards on the nuclear framework to prevent proliferation or accept that the elimination of such risk is simply impossible.

4.4 Conclusion

To conclude, SMRs could enhance nuclear energy's role during the Green Transition due to their passive safety systems and low power capacity, which make them more appealing to investors and the general public, compared to larger reactors. Also, since nuclear power is considered more eco-friendly than coal, carbon, or natural gas, SMRs present an alternative for countries that want to supply clean energy to their people but lack the financial means to construct a larger reactor.

However, Small Modular Reactors present some disadvantages as well. It is speculated, that despite being cheaper, they will not be particularly cost-effective. Of course, we cannot confirm this statement yet, as most of the projects are still under development. Furthermore, their construction time is rather slow, a delay potentially exasperated, by the obsolete regulatory framework. Finally, fears of nuclear proliferation might withhold potential investors from funding more SMR projects or any nuclear technology in general, especially during the turbulent geopolitical times that we live in.

5. CHAPTER FIVE: OPPORTUNITIES FOR EXPANDING THE USE OF NUCLEAR POWER

5.1 Electrification

Electrification is one of the most prominent characteristics of the Green Transition. From 2021 until 2030, approximately $1.1 trillion is invested annually in low-emission sources of electricity. To achieve net zero emissions however investments in net zero technology should reach at least 4 trillion annually.[84] Therefore, it comes as no surprise that the electricity sector is expected to be the first to achieve net zero emissions worldwide by 2040. After all, electricity is currently used complementary to or instead of fossil fuels for various intents and purposes, including but not limited to transportation and hydrogen production.

In the transportation sector, for instance, 8.1 million electric vehicles were sold in China in 2023. Another 3.2 million were bought by Europeans and 1.4 million by Americans. In other words, the number of EVs sold in the three regions increased by 35%, 20%, and 40%, respectively, compared to a year before.[85] Moreover, electrification is implemented in other means of public transportation such as buses.

Furthermore, electricity demand for heavy and light industrial activities, heating, cooking, etc., is expected to exceed 60,000 TW/h in 2050 (from only 23,000 TW/h)[86]. Under these circumstances nuclear energy could significantly boost low-emission electricity production more than renewable energy sources due to its ability to ensure coherent and high-quality power

[84] International Energy Agency. 2021. "Net Zero by 2050: A Roadmap for the Global Energy Sector." https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf.

[85] Gül, Timur, Araceli Fernandez Pales, Elizabeth Connelly, and International Energy Agency. 2024. "Global EV Outlook 2024." Report. International Energy Agency. https://iea.blob.core.windows.net/assets/a9e3544b-0b12-4e15-b407-65f5c8ce1b5f/GlobalEVOutlook2024.pdf.

[86] IEA, Nuclear Power and Secure Energy Transitions pdf

production. After all, nuclear power was a rather important electricity producer for regions like the EU, where nuclear plants generated around 22.8% of the total electricity produced in 2023[87].

5.2 The need to curb emissions from heat production

Increasing investments in cleaner energy sources for heating is essential to achieve the goals of the Paris Agreement. The sector, however, remains heavily dependent on fossil fuels. Coal and natural gas alone were used to produce 45% and 41% of the heat sold in 2021. Therefore, it is unsurprising that the sector accounted for 38% of energy-related CO_2 emissions worldwide in 2022, especially if we take into consideration that annual heat consumption expanded by 6% globally over 2017-2022[88].

Nonetheless, the demand for low-emission heat is also expected to increase rapidly over the coming years. Radical measures, such as the implementation of carbon pricing systems, provide economic incentives to lower the use of coal and gas. Governments use them to increase their revenues and consolidate their climate policies, while businesses and investors use them to assess risks and opportunities. Therefore, the attractiveness of clean energy increases, especially for energy-intensive industries. In this regard, renewable heat consumption is believed to rise more than 40% globally during 2023-2028[89].

However, the susceptibilities of RES provide an excellent opportunity for nuclear power to increase its share in global heat production.

[87] Eurostat, Nuclear energy statistics, Data from Jan. 2025, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Nuclear_energy_statistics

[88] IEA, Renewables 2023 Analysis and forecasts to 2028

[89] Bahar, Heymi, Renewable Energy Division, Yasmina Abdelilah, Ana Alcalde Báscones, Piotr Bojek, François Briens, Trevor Criswell, et al. 2024. "Renewables 2023." Report. Renewables 2023. https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf.

Even though nuclear power was a minimal source of heat in 2021 (providing only 0.1% of the total heat produced), it is still considered a promising field. In the EU, for example, the total production of nuclear heat in 2023 increased by 1.7% compared to 2022[90].

Furthermore, several other countries, mostly in northern Europe and in the former USSR region, have developed an interest in using nuclear power for district heating. Russia, for example, was the leading country for nuclear-powered district heating in 2021[91]. A year later, China started a major nuclear district heating development program, following the example of other countries, such as Bulgaria, the Czech Republic, Sweden, Hungary, Romania, Slovakia, Switzerland, and Ukraine[92]. Currently Beijing is working to expand this network. More specifically, the latter is expected to supply 4.6 million gigajoules of heat, which will save 410,000 tons of coal consumption and reduce CO_2 emissions by 760,000 tons.[93] Finally, in Finland, Steady Energy, a small modular reactor developer, signed an agreement with municipal energy company Keravan Energia in October 2024 to develop nuclear-powered district heating, making Keravan the third Finnish city to consider nuclear district heating[94].

Finally, when it comes to the industrial sector, nuclear power could be proven equally beneficial. After all, it is an excellent source of process heat for various applications, including desalination, synthetic and unconventional oil production, oil refining, biomass-based ethanol production, and, in the future, hydrogen production[95]. ("Nuclear Process Heat for Industry - World Nuclear Association") Additionally, using nuclear power for these industrial activities can present some financial benefits for the companies due to carbon pricing systems. It is therefore in their best interest to consider this alternative when available.

[90] Eurostat, Nuclear energy statistics, Data from Jan. 2025

[91] "Nuclear Plants Used for District Heating Globally| Statista." 2024. Statista. October 7, 2024. Accessed June 16, 2025. https://www.statista.com/statistics/1337195/nuclear-power-plants-providing-district-heating-worldwide/.

[92] Director General. 2023. "Nuclear Technology Review 2023. - IAEA" GC(67)/INF/4.

[93] "China's First Commercial Nuclear District Heating Scheme Expands." n.d. World Nuclear News. Accessed June 16, 2025. https://www.world-nuclear-news.org/articles/chinas-first-commercial-nuclear-district-heating-scheme-expands.s

[94] "Third Finnish City Considers SMRs for District Heating." n.d. World Nuclear News. Accessed June 16, 2025. https://www.world-nuclear-news.org/articles/third-finnish-city-considers-smrs-for-district-heating.

[95] "Nuclear Process Heat for Industry - World Nuclear Association." n.d. Accessed June 16, 2025. https://world-nuclear.org/information-library/non-power-nuclear-applications/industry/nuclear-process-heat-for-industry.

5.3 Increased interest in nuclear energy

Approximately 30 additional states are planning or have already begun nuclear power projects[96], including Serbia, Albania, Norway, Estonia, Turkey, Saudi Arabia, Qatar, Kuwait, Nigeria, Ghana, Senegal, Kenya, Indonesia, the Philippines, and Vietnam. As a result, dozens of nuclear reactors are currently under construction worldwide. With the words of IEA Executive Director Fatih Birol, «*More than 70 gigawatts of new nuclear capacity are under construction globally, one of the highest levels in the last 30 years».* [97]

At the same time, countries that already use nuclear power are planning to either expand or preserve their fleet. Washington, for instance, decided in 2022 to invest $6 billion to preserve its reactors as part of the Civil Nuclear Credit Program. Furthermore, $8 billion was to be allocated to demonstrate clean hydrogen hubs, including at least one dedicated to the production of hydrogen with nuclear energy[98].

As we saw earlier, the third unit of the Alvin W. Vogtle Electric Generating Plant was the first new reactor that began operating in the country in 2023 after decades[99]. A year later, on April 29, 2024, Unit 4 also began its commercial operation, making the Alvin W. Vogtle Electric Generating Plant the largest nuclear power plant in the country[100].

In May 2025 US President Donald Trump signed a series of executive orders with the goal of "re-establishing the United States as the global leader in nuclear energy." The aim of the

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[96] "Emerging Nuclear Energy Countries - World Nuclear Association." n.d. Accessed June 16, 2025. https://world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.

[97] 'A new era for nuclear energy beckons as projects', policies and investments increase, International Energy Agency (IEA), n.d. https://www.iea.org/news/a-new-era-for-nuclear-energy-beckons-as-projects-policies-and-investments-increase

[98] Nelson, Kimberly. 2025. "Hydrogen Hubs Receive Initial Funding, Begin to Take Shape - FCHEA." FCHEA. April 28, 2025. Accessed June 7, 2025. https://fchea.org/icym-hydrogen-hubs-receive-initial-funding-begin-to-take-shape/.

[99] "First U.S. Nuclear Reactor Built From Scratch in Decades Enters Commercial Operation in Georgia." 2023. NBC News. July 31, 2023. Accessed June 16, 2025. https://www.nbcnews.com/science/science-news/first-us-nuclear-reactor-built-scratch-decades-enters-commercial-opera-rcna97258.

[100] Granholm, Jennifer (May 31, 2024). "Remarks as Delivered by Secretary Jennifer M. Granholm on Startup of Vogtle Unit 4 and Growth of U.S. Nuclear Industry". Department of Energy. Archived

executive orders is to increase capacity from 100 GWe to 400 GWe by 2050, including the Department of Energy (DOE) prioritizing work "with the nuclear energy industry to facilitate 5 gigawatts of power uprates to existing nuclear reactors and have 10 new large reactors with complete designs under construction by 2030."

It is also important to note that large Tech corporations have also developed profound interest in nuclear power. Amazon for instance said it would invest $500 million in small modular nuclear reactors and Google declared plans to purchase power from SMRs owned by Kairos Power[101]. For nuclear plant operators and nuclear technology developers, the financial support of massive established customers could help keep old nuclear power plants open and push new technologies forward[102].

Finally, Constellation Energy, a power generation group with high expertise in nuclear power, has agreed to buy rival Calpine for around $27 billion. In a joint statement, the companies said that the deal *«creates the nation's largest clean energy provider»*[103]. Constellation Energy also signed a 20-year power purchase agreement for nuclear power from a previously shuttered unit at the Three Mile Island plant with Microsoft in 2024. These developments are indicative of a renewed interest in nuclear energy in the country.

When it comes to the UK, the 2022 Energy Security Strategy stressed the need to construct eight large new reactors, as well as small modular reactors, to achieve a nuclear generation capacity of 24 GW by 2050, or around 25% of the forecast electricity demand.

In the EU, France is the leading country in nuclear energy usage, with nuclear power accounting for 70% of its energy mix. Paris is also planning to start constructing six new reactors in 2028 while contemplating building eight more[104], including an SMR. After all, President Emmanuel Macron has stressed the importance of continuing to increase the supply of nuclear-generated

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[101] Bird, Lori. n.d. "US Clean Power Development Sees Record Progress, as Well as Stronger Headwinds." World Resources Institute. Accessed June 12, 2025. https://www.wri.org/insights/clean-energy-progress-united-states.

[102] Casey Crownhart (May 20, 2025), ''Can nuclear power really fuel the rise of AI?'' MIT Technology Review, https://www.technologyreview.com/2025/05/20/1116339/ai-nuclear-power-energy-reactors/

[103] Smyth, Jamie, Oliver Ralph, and Maria Heeter. 2025. "Constellation Energy to Buy Calpine in $27bn Deal as AI Fuels Power Demand." Financial Times, January 10, 2025. https://www.ft.com/content/7fe3ae45-d5a5-4355-876f-1aa66d931ef6.

[104] "Nuclear Power in France - World Nuclear Association." n.d. Accessed June 7, 2025. https://world-nuclear.org/information-library/country-profiles/countries-a-f/france.

electricity while also expanding RES projects to achieve net zero emissions. Specifically, Macron stated that *«Key to producing electricity in the most carbon-free, safest, and most sovereign way is precisely to have a plural strategy... to develop both renewable and nuclear energies {...} It is the most relevant choice from an ecological point of view, the most expedient from an economic point of view, and finally the least costly from a financial point of view.»*[105]

In Poland, which relies heavily on coal, the operation of the first nuclear reactor was delayed by three years. However, the decision to turn to nuclear energy is a milestone for Warsaw and underlines a decisive shift in the country's perception of alternative sources of energy. After all, more reactors are to be commissioned every 2-3 years up to a total of six[106]. Furthermore, in 2022, Warsaw agreed to deploy SMRs based on US technology to replace existing coal-fired and co-generation plants. Poland might be taking these measures due to the EU's «green» pressure. Nonetheless, this trend presents numerous opportunities for nuclear-related technologies.

Similarly, Netherlands, have also decided to expand their nuclear fleet[107]. In December 2021, the country's coalition government placed nuclear power at the heart of its climate and energy policy. Based on preliminary plans, two new reactors would be completed around 2035, and each would have a capacity of 1000-1650 MWe. The two reactors would provide 9-13% of the Netherlands' electricity production in 2035[108]. The debate concerning the appropriate site for the project will probably delay completion of the reactors. Regardless, it is very interesting that Copenhagen is now planning to increase the proportion of nuclear power in its energy mix after having only one operational reactor for many years.

[105] "Macron Sets Out Plan for French Nuclear Renaissance." n.d. World Nuclear News. Accessed June 7, 2025. https://world-nuclear-news.org/Articles/Macron-announces-French-nuclear-renaissance.

[106] "Nuclear Power in Poland - World Nuclear Association." n.d. Accessed June 7, 2025. https://world-nuclear.org/information-library/country-profiles/countries-o-s/poland.

[107] Proctor, Darrell, and Darrell Proctor. 2024. "Dutch Government Supports Four New Nuclear Reactors." POWER Magazine. June 6, 2024. Accessed June 16, 2025. https://www.powermag.com/dutch-government-supports-four-new-nuclear-reactors/.

[108] "Dutch Nuclear New Build Timeline Set to Slip." n.d. World Nuclear News. Accessed June 7, 2025. https://world-nuclear-news.org/articles/delays-appearing-in-dutch-nuclear-new-build-plans.

Finally, in Romania, the collaboration between Bucharest and the American company NuScale Power seems to pave the way for the country to be the first or at least one of the first countries in Europe to acquire a Small Modular Reactor (SMR)[109].

Besides the EU governments, Turkish president Recep Tayyip Erdogan has also declared that a trial energy production from the country's first nuclear power plant, in Akkuyu, will have begun by the end of 2025. He also declared that the plant would become fully commercial in 2028.

At last, Asia has been reporting astonishing nuclear activity over the years. For instance, there are currently 58 operable reactors in China, 24 in India, 33 in Japan, and 26 in South Korea, as well as 6 in Pakistan and Uzbekistan. At the same time, the total number of reactors under construction in the area amounts to 45, which accounts for about three-quarters of the reactors constructed worldwide. Simultaneously, there are firm plans to build about an additional 60[110]. In January 2025, Indonesia unveiled plans to build 20 new nuclear power plants, with the first set to come online by 2036[111].

These are just a few of the steps taken by governments worldwide to increase nuclear power use. Nonetheless, they can provide an important insight into the current nuclear renaissance.

5.4 Hydrogen Technology

Energy transition has sparked a growing global interest in alternative fuels. Consequently, it is not surprising that the demand for hydrogen surged recently, reaching 8.2 Mt in 2022[112].

[109] National Commission for Nuclear Activities Control (CNCAN), and Drăghici Madalina Terteci. n.d. '*Plans for Deployment SMR in Romania. Regional Workshop on Safety Benefits and Challenges in the Development of the Adoption of Small Modular Reactors'*.

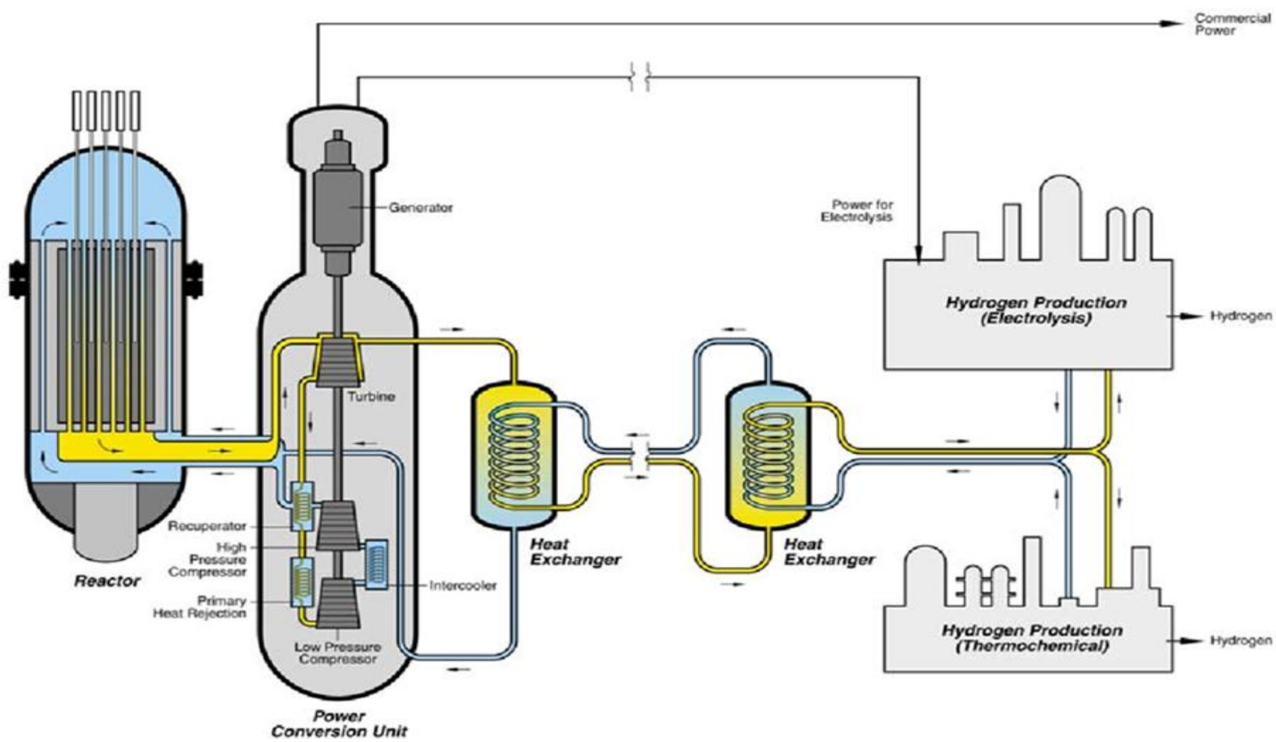
[110] "Asia's Nuclear Energy Growth - World Nuclear Association." n.d. https://world-nuclear.org/information-library/country-profiles/others/asias-nuclear-energy-growth.

[111] Kaitlyn Flynn Atomic Wars: Nuclear Energy Competition in Southeast Asia, The Diplomat n.d. https://thediplomat.com/2025/03/atomic-wars-nuclear-energy-competition-in-southeast-asia/

[112] "Hydrogen Demand | European Hydrogen Observatory." n.d. European Hydrogen Observatory. Accessed June 7, 2025. https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/end-use/hydrogen-demand.

Refineries account for the largest share of total hydrogen demand, comprising 57% and utilizing approximately 4.6 Mt of the fuel.

It is expected that the total demand for hydrogen worldwide will increase between 125 and 585 Mtpa by 2050[113]. In this scenario, nuclear power plants can play a fundamental role in meeting hydrogen demand,[114] especially considering the increasing importance of green hydrogen during the energy transition. Renewable sources of energy are often used to produce green hydrogen via electrolysis (Figure 13). However, nuclear power can also produce zero-carbon hydrogen through electrolysis, ensuring constant supply. China is currently the leading country in using the fuel.[115]



[113] Gulli, Chiara, Bernd Heid, Jesse Noffsinger, Maurits Waardenburg, and Markus Wilthaner. 2024. "Global Energy Perspective 2023: Hydrogen Outlook." McKinsey & Company. January 10, 2024. Accessed June 7, 2025. https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2023-hydrogen-outlook.

[114] "Hydrogen Production and Uses - World Nuclear Association." n.d. Accessed June 7, 2025. https://world-nuclear.org/information-library/energy-and-the-environment/hydrogen-production-and-uses.

[115] Olano, Maria Virginia. 2024. "Chart: Which Countries Are Leading the Green Hydrogen Race?" Canary Media, February 2, 2024. https://www.canarymedia.com/articles/hydrogen/chart-which-countries-are-leading-the-green-hydrogen-race.

Figure 13: Depiction of Nuclear-powered Electrolysis

Source: Arno A. Evers, Production of Electricity and Hydrogen from Nuclear

Electrolysis is the process of using electricity to split water into hydrogen and oxygen in specific unit called electrolyzer. At present, there are approximately a dozen electrolyzer projects of such under development in Canada, China, Russia, Sweden, the UK, and the USA, with a combined capacity of 250 MW.

Nonetheless, as we saw, constructing nuclear power facilities in a country that does not have any entails enormous upfront costs. In contrast, the rapid rollout of renewables is expected to push their capital cost even further down by 2030[116]. This lowers the levelized cost of producing hydrogen from renewable energy sources, especially in regions with high renewable energy potential, such as the US, parts of Europe, China, India, and the Middle East, where costs are projected to fall to $1.1 per kilo of hydrogen by 2040.

5.5 Russian invasion of Ukraine

After the Russian invasion of Ukraine, the cost of natural gas skyrocketed. This development was considered crucial, since the low cost of natural gas is seen as the greatest challenge against expanding the use of nuclear power. As a result, some countries that were considering shutting down all or several of their reactors decided against it amidst the looming fears of energy insecurity.

For instance, in September 2022, Berlin decided to keep Isar 2 and Neckarwestheim 2 on standby until mid-April 2023[117]. Although the country ultimately proceeded with its planned phase-out of nuclear power, the temporary extension of the two reactors' lifespans highlighted the stabilizing role of nuclear energy during turbulent times and crises. This may explain why the

[116] International Energy Agency, Nuclear Power and Secure Energy Transition

[117] "Nuclear Power in Germany - World Nuclear Association." n.d. Accessed June 9, 2025. https://world-nuclear.org/information-library/country-profiles/countries-g-n/germany.

new German Chancellor, Friedrich Merz, is considering the possibility of restarting the most recently decommissioned reactors, a decision that enjoys support from most citizens.

In addition to Germany, many other countries have made similar decisions after the shock that followed the Ukraine war. Unsurprisingly, France was among these countries, announcing its plan to extend the lifetimes of all nuclear reactors that are eligible for extension while also constructing new ones, as previously mentioned. Belgium has also decided to extend the operational lifetimes of the reactors at Doel 4 and Tihange 3 until 2035[118]. In Hungary, the lifespan of all reactors at the Paks nuclear plant is expected to be extended by 20 years[119]. As for Spain, despite earlier plans to phase out nuclear energy, the country has chosen to prolong the lifespans of its reactors by 5 to 10 years. Consequently, Madrid will remain engaged in nuclear energy for at least another decade. Finally, Romania plans to extend the life of Cernavoda Unit 1 by 30 years, until 2059.[120]

From the aforementioned examples, it is evident that states will prioritize extending the lifespan of their reactors over building new facilities, as this approach offers them greater flexibility and financial benefits. The capital costs for most extension projects range between $500 and $1,100 per kilowatt, substantially less than the $2.000 per kilowatt required for nuclear energy to compete with RES. In addition, lifespan extensions are not long-term binding, unlike constructing new facilities which takes a lot of time, making it a very attractive choice for countries that are unsure about their nuclear plans and are testing whether it is viable to continue supporting their fleet.

5.6 Nuclear power and shipping industry

[118] Keating, Dave. 2022. “Will the Ukraine War Change Europe’s Thinking on Nuclear?” Energy Monitor, March 24, 2022. https://www.energymonitor.ai/sectors/power/will-the-ukraine-war-change-europes-thinking-on-nuclear/.

[119] “Hungary Aims to Extend Life of Paks Nuclear Plant by 20 Years.” n.d. World Nuclear News. Accessed June 9, 2025. https://www.world-nuclear-news.org/articles/hungary-aims-to-extend-life-of-paks-nuclear-plant.

[120] “Nuclear Power in Spain - World Nuclear Association.” n.d. Accessed June 9, 2025. https://world-nuclear.org/information-library/country-profiles/countries-o-s/spain.

The shipping industry accounts for 3% of the total GHG emissions[121]. This figure is concerning if we consider that unless radical changes are made, this percentage could climb to 10% by 2050. In this regard, nuclear-powered commercial ships can play a leading role in reversing this negative prospect.

Although the use of nuclear energy in shipping began in the 1950s, it did not prevail commercially due to excessive costs and regulatory barriers. Currently, it primarily powers submarines and surface warships, and only a few commercial vessels. However, as the pressure to achieve net-zero emissions by 2050 increases, and online trading becomes increasingly popular, a potential expansion of nuclear-powered commercial ships could be quite useful due to some of their inherent advantages.

To begin with, nuclear propulsion allows ships to move faster without a substantial increase in cost. This helps companies reduce their transportation times, which, as a result, also increases the clients' satisfaction. The transportation time is also shorter for nuclear-powered commercial ships due to the absence of fuel tanks and an internal combustion engine. This allows more cargo to be transported, which means that more products can be delivered each time a ship sails.

Similar to nuclear reactors, nuclear-powered commercial ships, do not need frequent refuelling. Many of them can operate for up to 7 years without needing new fuel. At the same time, recent technologies suggest that some ships may even achieve continuous operation for as long as 20 years.

At last, nuclear-powered commercial ships, could contribute greatly to the decarbonization of the shipping industry, due to the clean nature of nuclear power.

All these advantages make nuclear propulsion ideal for long-distance transport of large cargo. In this regard, respected maritime powers, including Greece, can play a leading role in establishing nuclear energy in shipping. Countries such as the USA, Russia, and China, along with shipping companies like Maersk and NYK Line, shipyards such as Hyundai KSOE, and technology

[121] Environment, Transport &. 2024. "Climate Impact of Shipping." T&E. May 7, 2024. Accessed June 9, 2025. https://www.transportenvironment.org/topics/ships/climate-impact-shipping.

startups like CORE POWER, Seaborg, and Copenhagen Atomics, have already begun working intensively toward this new era of nuclear propulsion[122].

5.7 Conclusions

Nuclear power can benefit from many current developments.

To begin with, as a great supplier of electricity, it is exceptionally useful as electrification prevails during the Green Transition. In 2023, around 22.8% of the total electricity produced was generated by nuclear power plants.

Heating is another crucial aspect of the Green Transition, as it relies heavily on fossil fuels. Coal and natural gas alone produced 45% and 41% of global heat in 2021, accounting for 38% of energy-related CO_2 emissions. However, as efforts to achieve net-zero emissions intensify, we expect the demand for low-emission heat to increase rapidly. Nuclear power is considered a promising field for district heating, and countries like Bulgaria, Canada, China, the Czech Republic, Germany, Hungary, India, Japan, Kazakhstan, Russia, Slovakia, Sweden, Switzerland, and Ukraine have found it convenient to apply nuclear heat for district heating or industrial processes, or both, in addition to electricity generation.

About 30 states are considering, planning, or starting nuclear power programs. Interest towards nuclear power has also increased among countries that already use it as a substantial or supplementary source of electrification.

France is the country that uses nuclear energy the most, with President Macron stating that it is the most relevant choice from an «ecological, economic, and financial point of view».

The UK is opting to create eight large new reactors and small modular reactors to achieve a nuclear generation capacity of 24 GW by 2050, or around 25% of the forecast electricity demand.

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[122] Γ. Λάσκαρης, Ι. Κουράσης, Σ. Χειρδάρης, Α. Πλατιάς «Πυρηνική Ενέργεια στη Ναυσιπλοΐα, Μια Νέα Τεχνολογική Επανάσταση στην Ναυτιλία και ο Ρόλος της Ελλάδας», Ιούνιος, 2025 Deon Policy Institute

Washington has invested $6 billion to preserve existing American reactors and a total of $3.2 billion in two nuclear projects over seven years.

Poland's decision to start its nuclear program is a huge milestone, which plans to commission its six reactors in total, while the Netherlands, has also decided to expand their nuclear fleet.

In Asia, the use of nuclear power has taken off. There are currently 58 operable reactors in China, 24 in India, 33 in Japan, 26 in South Korea, and 6 in Pakistan and Uzbekistan. The total number of reactors under construction in the region is 45, accounting for about three-quarters of the reactors worldwide. Indonesia unveiled plans to build 20 new nuclear power plants in January 2025, with the first set to come online by 2036. Furthermore, large tech corporations have developed profound interest in nuclear power, which will likely push its further development.

The rise of hydrogen's demand can be confronted with the help of nuclear power as well. However, building a reactor entails immense upfront costs, which decreases the attractiveness of nuclear-produced hydrogen compared to renewable energy sources.

The Russian invasion in Ukraine led to a surge in natural gas costs, making nuclear power more attractive. Many countries have decided to extend the lifespan of their nuclear reactors, including Germany, France, Belgium, Hungary, Spain, and Romania.

Finally, nuclear power has become an important alternative in the shipping industry, as nuclear-powered commercial ships could play a significant role in reducing GHG emissions in the sector. They are faster, more cost-effective, and can operate for up to 7 years without needing refuelling, which makes them an attractive choice for long-distance transport of large cargo. Countries like the USA, Russia, and China are working towards this new era of nuclear propulsion, and Greece could play an important role in achieving this development.

6. CHAPTER SIX: CHALLENGES FOR NUCLEAR ENERGY

6.1 Low Cost of Natural Gas and RES

The primary rival of nuclear power is natural gas. Despite a rise in its cost following the Russian invasion of Ukraine, natural gas remains relatively affordable. Additionally, natural gas-fired power plants can be constructed more quickly than nuclear power plants. Their construction also requires less specialized expertise compared to nuclear power plants, making it easier to find workers willing to accept lower salaries. This results in reduced labor costs and, consequently, lower construction costs for natural gas-fired plants.

Furthermore, since most countries have been using seamlessly natural gas for years, its market has had ample time to develop. As a result, there are numerous suppliers worldwide, and the existing legislative framework is more up to date compared to that of nuclear power. The latter also encourages even more potential suppliers to enter the market, which enhances competition and increases the economic benefits for consumers.

Consequently, many states choose to overlook the long-term economic advantages associated with the low operational costs of nuclear power plants in favor of the short-term benefits offered by natural gas.

On the other hand, establishing new RES projects is less costly, as we have seen in previous chapters. Also, renewable energy is subsidized in various ways around the world, which further diminishes the cost for investors. In the United States, a combination of government financial incentives and market conditions has led to an increase in renewable electricity generation[123]. In 2023, for instance, renewables surpassed coal in energy generation[124].

[123] "Renewable Energy Explained - Renewable Portfolio and Clean Energy Standards - U.S. Energy Information Administration (EIA)." n.d. Accessed June 12, 2025. https://www.eia.gov/energyexplained/renewable-sources/portfolio-standards.php.
[124] U.S. Energy Information Administration (EIA) (2024) Monthly Energy Review May 2024. https://www.eia.gov/totalenergy/data/monthly/index.php

The EU has also created many support schemes in favor of renewable energy[125], which explains the rapid increase in the deployment of RES projects. Since 2022, wind capacity in the Union has increased by 234 GW, while new solar energy capacity installed has reached 338 GW[126]. In 2023, renewable energy represented 24.5% of energy consumed in the EU, up from 23.0% in 2022.[127] Renewable energy projects are also heavily encouraged in the Union as essential measures to diversify the bloc's energy mix. Especially in regions where weather conditions favor the use of renewable energy sources, building photovoltaic stations and wind turbines is far easier and more cost-effective than constructing a nuclear power plant. the Union's ambition to scale up nuclear energy as part of its 2050 net zero emission goal is estimated at €241 billion, posing huge funding challenges[128].

We can infer that, the lower construction costs associated with renewable energy sources (RES) and natural gas appear to compromise the viability of nuclear power projects. Given that renewable energy projects receive significant subsidies as part of the Green Transition and that natural gas is already commonly utilized as a transitional fuel, the future of nuclear power seems uncertain for many countries.

6.2 Limited public acceptance

Nuclear power is often viewed by the public as dangerous or unstable due to nuclear accidents, and its association with nuclear weapons.[129] Indeed nuclear accidents can be alarming because of

[125] "Support Schemes for Renewable Energy." n.d. Energy. Accessed June 12, 2025. https://energy.ec.europa.eu/topics/renewable-energy/financing/support-schemes-renewable-energy_en.

[126] "REPowerEU." 2022. European Commission. May 18, 2022. Accessed June 12, 2025. https://commission.europa.eu/topics/energy/repowereu_en#producing-clean-energy.

[127] "Renewable energy statistics – Eurostat, Data extracted in December 2024". n.d. Accessed June 12, 2025. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics

[128] "John Ainger Europe's Nuclear Ambitions Face €241 Billion Funding Challenge", Bloomberg n.d. Accessed June 12, 2025 https://www.bloomberg.com/news/articles/2025-06-12/europe-s-nuclear-ambitions-face-241-billion-funding-challenge?srnd=homepage-uk

[129] "Advantages and Challenges of Nuclear Energy." n.d. Energy.Gov. Accessed June 16, 2025. https://www.energy.gov/ne/articles/advantages-and-challenges-nuclear-energy.

the significant short- and long-term effects of radiation on public health and the environment. However, as previously mentioned, studies indicate that the actual impact, while profound, may not be as devastating as commonly believed.

For example, after the disasters at Fukushima and Chernobyl, the evacuation of the affected areas caused significantly more distress for the former residents than the accidents themselves. In addition to the psychological impact of leaving their homes, the stigmatization of the evacuated population sparked more problems of social nature to the affected individuals[130], as we mentioned in chapter 3. Moreover, many pregnant women in Europe were advised to consider abortions due to the unprecedented scale of the Chernobyl disaster, which raised concerns about potential irreversible complications from radiation exposure on fetuses. This, of course, heightened fears regarding the consequences of nuclear accidents, even though no significant increase in birth defects was reported.

Another indication of the public's apprehension regarding the long-term effects of nuclear accidents arose when Japan began releasing treated water from the Fukushima nuclear power plant into the nearby sea on August 24, 2023. Although the International Atomic Energy Agency (IAEA) had previously clarified that Tokyo's plan for the water discharges adhered to international safety standards and that its radiological impact would be insignificant for both people and the environment, neighboring countries such as China protested. Beijing described the discharge as *"a major nuclear safety issue with cross-border implications"* and subsequently refused to import various aquatic products from Tokyo.

The two countries eventually reached an agreement regarding the issue in August 2024[131]. This agreement stipulated that Japan would allow long-term international monitoring arrangements and permit stakeholders to conduct independent sampling and monitoring. However, even after the deal, Beijing remained apprehensive. Mao Ning, spokesperson for the Chinese foreign ministry, emphasized that the blanket ban on Japanese aquatic products would not be lifted

[130] "What are the effects of nuclear accidents? - World Nuclear Association" n.d. Accessed June 12, 2025. https://world-nuclear.org/nuclear-essentials/what-are-the-effects-of-nuclear-accidents.

[131] Nicolas, Jino. 2024. "China, Japan Reached Agreement in August on Fukushima Water Discharge." BusinessWorld Online. September 20, 2024. Accessed June 16, 2025. https://www.bworldonline.com/world/2024/09/20/622910/china-japan-reached-agreement-in-august-on-fukushima-water-discharge/.

immediately. Unsurprisingly, it was not until May 2025 that Beijing agreed to set in motion the procedure to resume seafood imports from Japan[132].

These developments illustrate how ordinary people, well-educated experts, and even governments can fall victim to misinformation and false data. Global hysteria, often sparked by tragic events and amplified by the entertainment industry, is crucial to understanding why nuclear power remains a controversial topic among individuals.

6.3 Constrained Russian uranium imports

As more countries express an interest in developing nuclear plants and reactors, the demand for uranium is expected to reach 130,000 tons by 2040. This amount is almost double the 67,500 tons of uranium required annually by all operating nuclear reactors worldwide today[133].However, western countries could face difficulties in acquiring the fuel due to their stance against Russia after Moscow's unjustified invasion of Ukraine.

To elaborate, in Chapter 2, we mentioned that the European Union is planning to cease all Russian energy imports, including gas and uranium, which were previously permitted. This development could be particularly challenging for the bloc, as in 2024, the EU still imported more than 2,800 tons of uranium in enriched or fuel form from Russia, with an estimated worth of €700 million[134].

From this information, we can infer that, although significantly reduced, some Russian energy imports continue to be an integral part of the bloc's energy mix. This is likely due to the Union's reliance on uranium imports to sustain its nuclear fleet. For many years, Russia has been

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[132] "China agrees to begin steps to resume Japanese seafood imports: Tokyo – KYUODO news" n.d. Accessed June 12, 2025. https://english.kyodonews.net/news/2025/05/267eb10b4cf5-update1-china-agrees-to-begin-steps-to-resume-japanese-seafood-imports-tokyo.html?phrase=cherry%20blossom&words=

[133] "Supply of Uranium - World Nuclear Association." n.d. https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.

[134] 'Questions and answers on the EU Roadmap to phase out Russian energy imports', European Commission, https://ec.europa.eu/commission/presscorner/detail/en/qanda_25_1132

regarded as a reliable supplier of nuclear material for Europe, because of its proximity to the EU and abundant uranium resources. Additionally, with 19 Soviet-designed VVER reactors still operational in the Union, it's not surprising that nearly all their fuel comes from Rosatom[135]. For example, France, where nuclear power constitutes almost 70% of the country's electricity generation, continues to rely heavily on Moscow for uranium.

It is evident that ceasing Russian uranium imports will be more challenging than stopping other sources of energy imports. Due to sanctions, Russian coal imports, for example, are now minimal, accounting for only 3% of the bloc's total energy imports. Therefore, it is rather easy to cut them down completely. On the other hand, Russian uranium imports account for 38% of total uranium imports in the EU, a percentage significantly more difficult to eliminate in a short period of time.

Therefore, Brussels must be excellently prepared. Fortunately, natural uranium is abundant, and Russia is not the only available provider. Trusted suppliers, including Canada, Australia, Kazakhstan, and Namibia, are already accessible. In 2023, for instance, the greatest provider of uranium for the EU was Canada[136]. Also, Australia could prove to be an exceptionally important uranium supplier, as it is thought to contain 28% of the world's uranium supply[137]. Nonetheless, if new collaborations do not develop quickly and a transitional period is not established, EU countries may struggle to adjust to the new circumstances.

Finally, it is important to recognize that EU nations will not be the only ones facing severe repercussions if they stop Russian uranium imports. All Western countries that depend on Russian uranium and choose to impose sanctions on Moscow's energy could encounter similar challenges unless they are adequately prepared at a legal and practical level.

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[135] "The Brussels Times." n.d. Accessed May 22, 2025. https://www.brusselstimes.com/1571208/does-record-breaking-uranium-imports-from-russia-reveal-europes-continued-energy-vulnerability.

[136] Statista. 2024. "EU Imports of Uranium 2023, by Country of Origin." August 21, 2024. Accessed May 26, 2025. https://www.statista.com/statistics/1147442/imports-of-uranium-to-eu-by-country/.

[137] "Supply of Uranium - World Nuclear Association," n.d. https://world-nuclear.org/information-library/nuclear-fuel cycle/uranium-resources/supply-of-uranium#uranium-availability.

6.4 Conclusions

The nuclear industry faces significant threats from natural gas and renewable energy sources, which are both inexpensive and require less specialization. Also, people often view commercial nuclear power as dangerous due to its association with nuclear weapons and accidents. However, research has shown that the impact of accidents, while important, is not as severe as previously believed. New concerns regarding the long-term effects of nuclear accidents have emerged following the release of treated water from the Fukushima nuclear power plant into the sea. China and Japan reached an agreement in August 2024, allowing long-term international monitoring arrangements and independent sampling and monitoring. Beijing, however, remained apprehensive and agreed to resume seafood imports from Japan in May 2025.

Finally, constraining Russian uranium imports is another challenge for Western countries, as they rely on uranium imports to sustain their nuclear fleet. The EU, in particular, plans to cease all Russian energy imports, including gas and uranium ones, but this could be particularly challenging due to Brussels' dependence on Russian uranium imports. However, with precise planning, this goal can be achieved, as natural uranium is abundant, and countries like Canada, Australia, Kazakhstan, and Namibia are already available suppliers. Nonetheless, new collaborations must form soon; otherwise, EU countries may face difficulties adjusting to the new reality.

7. CHAPTER SEVEN: WHICH COUNTRIES COULD REALISTICALLY US NUCLEAR POWER AS A PRIMARY FUEL?

7.1 Which countries generate the largest/lowest amount of nuclear electricity

We have established so far that 9% of global electricity production comes from nuclear energy, which also accounts for 25% of low-carbon electricity[138]. However, each state's nuclear power production differs according to the potency of their fleet.

In 2023, the USA, China, and France produced the largest amounts of nuclear power, with annual production of 779.19 TW/h, 406.48 TWh, and 323.77 TWh, respectively. Unsurprisingly, these three countries have the highest number of operational reactors. Specifically, the US have 94 in 2023, China 58, and France 57.

In chapter 5 we talked about the US's growing interest in nuclear power and France's potent nuclear fleet. It is significant, however, to stress that Beijing is also expanding its nuclear capacity.

In 2022, nuclear power accounted for 5% of Chinese electricity[139], a promising increase from 2015, when it represented only 3%. Currently 28 reactors are under construction[140] in the massive country while investments to upgrade the existing ones intensify. This development has resulted in unprecedented levels of nuclear electricity production. For instance, Daya Bay Nuclear Power Plant produced over a trillion kilowatts of clean energy on 29 April 2025, according to China General Nuclear Power Group (CGN). The achievement was considered a huge «green» milestone because its positive impact on the environment was thought to be

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[138] "Nuclear Power in the World Today - World Nuclear Association." n.d. Accessed June 13, 2025. https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.

[139] "Nuclear Power in China - World Nuclear Association." n.d. Accessed June 13, 2025. https://world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.

[140] "Top 15 Nuclear Generating Countries – Nuclear Energy Institute" n.d. Accessed June 13, 2025 https://www.nei.org/resources/statistics/top-15-nuclear-generating-countries

equivalent to reforesting a land area of 2.25 million hectares. It is no wonder, therefore, that some specialists speculate that China will surpass the EU's and USA's production by 2030, once the reactors under construction begin their commercial operation.[141] Simultaneously, China aims to become the most important supplier of affordable nuclear reactors in the world. This step, however, is difficult to achieve, as Russia remains prevalent in the reactor export market.

In contrast, the nuclear production in Armenia, the Netherlands, and Slovenia was 2.51 TW/h, 3.77 TW/h, and 5.33 TW/h, respectively[142]. The fact that each of these countries only has one operational reactor explains their small nuclear power production.

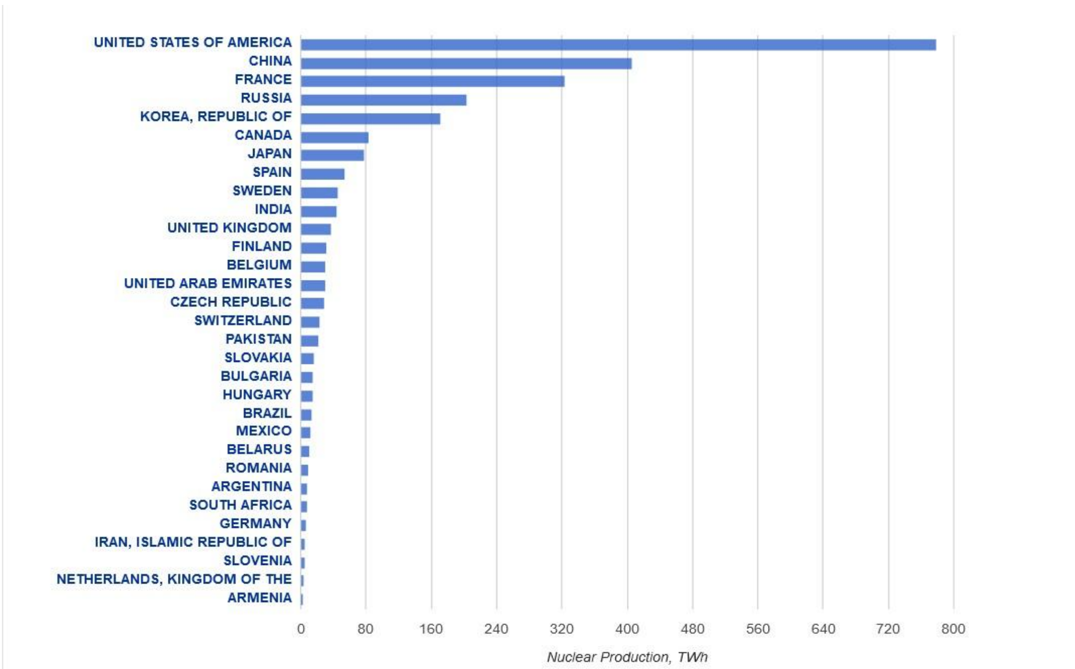

Figure 14: Nuclear Generated Electricity Production in TWh

Source: "PRIS - Miscellaneous Reports - Nuclear Share." n.d. Accessed June 13, 2025. *https://pris.iaea.org/pris/worldstatistics/nuclearshareofelectricitygeneration.aspx*

It is, however, important to stress that if a country's nuclear-generated is small in numbers, that does not necessarily mean that the share of nuclear power in their energy mix is small, as well,

[141] Writer, Staff. 2025. "China to Surpass U.S., Europe in Nuclear Energy Capacity by 2030: IEA." Nikkei Asia, January 16, 2025. https://asia.nikkei.com/Business/Energy/China-to-surpass-U.S.-Europe-in-nuclear-energy-capacity-by-2030-IEA

[142] "PRIS - Miscellaneous Reports - Nuclear Share." n.d. Accessed June 13, 2025. https://pris.iaea.org/pris/worldstatistics/nuclearshareofelectricitygeneration.aspx.

and vice versa. For example, even though the largest amount of nuclear electricity was produced in the US in 2023, the share of nuclear power in the country's electricity mix was only 18.6%. On the other hand, Armenia's share of nuclear power in its electricity mix was 31.1%, despite having the lowest nuclear electricity production among the countries examined during the period of our interest.

France ranked first, with nuclear power accounting for 64.8% of its electricity mix (Figure 15). Slovakia followed closely at 61.3%. Hungary came third, with a nuclear share of 48.8%, while Finland was fourth at 42%. Belgium rounded out the top five with a nuclear share of 41.2%.

COUNTRY	PERCENT OF TOTAL ELECTRICITY GENERATED BY NUCLEAR IN 2023
France	64.8
Slovakia	61.3
Hungary	48.8
Finland	42.0
Belgium	41.2
Czech Republic	40.0
Slovenia	36.8
Switzerland	32.4
South Korea	31.5
Armenia	31.1
Belarus	28.6
Sweden	28.6
Spain	20.3
United Arab Emirates	19.7

SOURCE: INTERNATIONAL ATOMIC ENERGY AGENCY; U.S. ENERGY INFORMATION ADMINISTRATION
UPDATED: JULY 2024

Figure 15: Countries that use nuclear energy the most

Source: "PRIS - Miscellaneous Reports - Nuclear Share." n.d. Accessed June 13, 2025. *https://pris.iaea.org/pris/worldstatistics/nuclearshareofelectricitygeneration.aspx*

It appears that Paris and Bratislava already use nuclear power the most to meet the electricity demand of their population. It is also safe to infer that, once the construction of nuclear projects is complete, Hungary, Finland, and Belgium could come close to the same milestone.

Conversely, despite producing huge amounts of nuclear electricity, the USA, China, and even Russia are far from using it as a primary fuel, most likely due to the excessive energy demand of their huge populations and industrial activity (especially in China and the USA). It is beyond the shadow of a doubt that covering this huge demand mainly with nuclear power is quite difficult, as it requires that many more reactors be created rather soon. Such investments, however, not only require hundreds of billions of dollars in capital, but also the projects will not likely finish in time. SMRs could present a more viable option; nonetheless, they are still costly, and their effectiveness has not been sufficiently proven yet.

Despite the challenging circumstances, Moscow is willing to take risks. More specifically, it is planning to raise its share of nuclear-generated electricity to 23.5% by 2042, according to a draft plan released in September 2024. To achieve this goal, the document includes a provision for constructing 34 nuclear power units by 2042[143]. However, the ongoing war between Russia and Ukraine could jeopardize this initiative. Western sanctions have limited Moscow's trading partners, thus reducing its revenues, part of which could potentially fund its nuclear expansion. Ultimately, while a decision has been made to enhance the capacity of the Russian nuclear fleet, it is uncertain whether Moscow will follow the original plan.

China has been actively working to boost its nuclear exports through the Belt and Road Initiative (BRI). In 2016, the China National Nuclear Corporation (CNNC) announced its goal to capture 20%–30% of the market share in 40 BRI countries by 2030, which translates to approximately 30 reactors[144]. We must also note that in China, there are currently 30 nuclear reactors under construction, which is particularly impressive, given that this number worldwide is close to 70. Beijing has expressed its ambition to expand its nuclear-related exports across a wider region; however, Moscow's established nuclear influence in that area complicates this effort.

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[143] "Nuclear Power in Russia - World Nuclear Association." n.d. Accessed June 13, 2025. https://world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.

[144] Li, Aitong, Yahan Liu, and Zongyao Yu. 2023. "China's Nuclear Exports: Understanding the Dynamics Between Domestic Governance Reforms and International Market Competition." Energy Research & Social Science 103 (August): 103230. https://doi.org/10.1016/j.erss.2023.103230.

When it comes to the USA, Washington has set a target to quadruple nuclear capacity by 2050.[145] At the same time, the profound interest of large companies, such as Microsoft and Amazon, to invest in SMR technologies is crucial for their expansion. In this regard, we can expect that Washington will probably continue to play a leading role in nuclear generation capacity in the coming years.

To summarize, according to their share of nuclear generated electricity France and Slovakia are already using nuclear power as a primary fuel and are qualified to continue using it as such during energy transition. On the other hand, Hungary, Finland and Belgium are slowly pacing towards this direction.

Russia China and the USA, on the contrary, while generating huge amounts of electricity from nuclear power, are still not using it as a primary fuel, as the domestic demand is massive, and to cover it would require inviable investments. However, they appear eager to take many steps necessary to increase their nuclear electricity production.

7.2 Russia VS China

Previously, we talked about how the USA will likely continue generating the largest amount of nuclear power in total numbers for a long time. However, it would be interesting if we tried to predict the dynamic between Russia, the most well-established exporter of nuclear-related items, and China, the fastest-growing nuclear-generating country.

As we saw, China's ambition to be the most prolific exporter of cheap nuclear technology is curbed to some degree by Russia, which, through Rosatom, still holds a dominant position in nuclear reactors' exports. Specifically in 2023, Russia was the country that had exported the most nuclear reactors, the estimated value of which was over $1.1 billion[146]. This data is particularly

[145] "Nuclear Power in the USA - World Nuclear Association." n.d. Accessed June 13, 2025. https://world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power

[146] "The Observatory of Economic Complexity." n.d. The Observatory of Economic Complexity. Accessed May 24, 2025. https://oec.world/en/profile/bilateral-product/nuclear-reactors/reporter/rus.

impressive considering the unfavorable conditions Moscow's exports have been facing after Russian troops invaded Ukraine.

To understand the magnitude of Moscow's influence on the nuclear reactor export market, we could use some examples. From 2009 to 2018, Russia unsurprisingly won 23 out of the 31 orders placed worldwide[147]. After all, it has been successfully advertising its nuclear deals for many years by emphasizing the long-term cost-effectiveness of nuclear plants due to their high lifespans that permit cost amortization. Also, Moscow provides all technical services and sells power to local utilities or governments through a "build, own, and operate" program. This approach has been particularly beneficial for less technologically developed countries that seek to harness the advantages of civilian nuclear power but lack the resources and scientific expertise to do so. A recent example of this is the nuclear cooperation agreement signed on January 14, 2025, between Rosatom and EVN, Vietnam's state power utility [148].

Conversely, in 2023, China emerged as the leading importer of nuclear reactors, with a total import value of $695 million. Given this context, Beijing is not yet positioned to directly compete with Moscow in the export of nuclear reactors, as China continues to rely heavily on imports. Some may argue that this reliance stems from Beijing's significant investments in expanding its domestic nuclear fleet, while Moscow has not been as proactive in this area. Regardless, Russia maintains a greater degree of independence in this field compared to China.

When it comes to domestic production, Russia is among the countries that generate the highest amount of electricity. For instance, the Akademik Lomonosov floating nuclear power plant in Russia's Arctic Chukotka had reportedly generated 1 billion kilowatts of nuclear electricity in total by January 2025, after only five years of commercial operation.[149] However, investments to expand the country's nuclear fleet had stalled for quite a while before the Kremlin announced its ambition to construct as many as 34 new reactors by 2042. China, on the other hand, is actively

[147] Li, Aitong, Yahan Liu, and Zongyao Yu. 2023. "China's Nuclear Exports: Understanding the Dynamics Between Domestic Governance Reforms and International Market Competition." Energy Research & Social Science 103 (August): 103230. https://doi.org/10.1016/j.erss.2023.103230.

[148] Yahyai, Oman Al. 2025. "Vietnam and Russia Sign Agreement to Expand Nuclear Energy Cooperation." Euronews, January 14, 2025. https://www.euronews.com/2025/01/14/vietnam-and-russia-sign-agreement-to-expand-nuclear-energy-cooperation.

[149] "Russia's Floating Nuclear Power Plant Passes One Billion kWh." n.d. World Nuclear News. 16 January 2025 https://www.world-nuclear-news.org/articles/russias-floating-nuclear-power-plant-passes-one-billion-kwh.

expanding its nuclear fleet and has become the second most prolific nuclear power-generating country, surpassed only by the USA.

Uranium capacity is another important matter to consider when we compare the two countries. Russia controls 22% of the world's uranium conversion capacity and almost half of its enrichment capacity[150]. That, combined with Russia's geographical proximity to both Europe and Asia has made it the ideal trading partner to countries from both continents. On the other hand, while China may not possess as many natural resources as Russia, it has achieved a degree of autonomy in various aspects of the nuclear fuel cycle. Beijing's policy aims for one-third of its uranium supply to come from domestic sources, one-third from Chinese investments in foreign mines, and one-third from the open market[151]. In absolute numbers The World Nuclear Association estimates that China's uranium conversion capacity is approximately 15,000 tons annually. As a result, Beijing could potentially play an important role in the uranium export markets, if it continued to expand its capacity.

An excellent opportunity for Beijing arises from the EU's plan to completely stop energy imports from Russia, including enriched uranium. However, the EU has been heavily reliant on uranium imports to sustain its nuclear fleet, and Russian uranium has played a significant role in the bloc's supply. If Russian imports cease, a substantial supply gap will emerge, making it crucial for alternative sources to be identified. China could take advantage of this situation to enhance its cooperation with European countries. After all, Beijing has previously signed various energy agreements with European states, including renewable energy projects deals with Athens, and is also importing nuclear reactors from France. Nonetheless, it is important to note that China maintains relatively good relations with Russia, which raises concerns among European officials. This does not necessarily mean that the Brussels-Beijing relationship will be disrupted, as both parties share common goals regarding energy transition. However, it remains uncertain to what extent EU nations are willing to overlook China's stance and engage in close cooperation with

[150] Krellenstein, James, and Garrett Wilkinson. n.d. "Expanding U.S. Uranium Enrichment: Ending Global Dependence on Russian Nuclear Fuel and Paving the Way for Deep Decarbonization."
[151] "China's Nuclear Fuel Cycle - World Nuclear Association." n.d. https://world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.

the world’s second-largest economy. (Further details on EU-China relations will be discussed in chapter 8).

Aside from their relationship with the EU, it would be interesting to compare the prospects of cooperation between the countries of interest and the USA.

The Beijing-Washington relationship has been rather tumultuous since President Trump announced huge tariffs against China. Although discussions are ongoing about the issue, the two countries still have a long way to go in bridging their differences and achieving any substantial cooperation, let alone in the sensitive area of nuclear power.

Russian-American relations is another chapter of its own. The two nations have consistently regarded each other with distrust, rarely demonstrating a desire for deep-rooted collaboration. Their diplomatic relations reached a record low after the Russian invasion of Ukraine, which the Biden administration condemned. Although President Trump has been more lenient toward Russian President Vladimir Putin, the unsuccessful attempts at peace negotiations between Moscow and Kyiv, with U.S. mediation, appear to further damage the relationship between the two nuclear superpowers.

To conclude, both Russia and China are important players in the nuclear market. Some analysts suggest that Beijing may surpass Moscow's dominance in the nuclear export market due to the Ukraine war, which has reduced Moscow’s revenues thus its ability to put into effect its plans to construct new reactors. However, others argue that this transition may be challenging due to Russia's established influence in nearby nuclear markets. Europe could play a crucial role in the potential expansion of Chinese nuclear exports, particularly because the European Union relies heavily on uranium imports, which are set to be banned from Russia. Nevertheless, it remains uncertain to what extent China can effectively replace Russia in this regard.

7.3 The aging fleet creates expansion issues

To determine whether some Western countries with well-established nuclear fleets continue to generate a significant amount of nuclear power, it is important to consider their views on reviving their aging fleets. This is important because, as we mentioned, extending the lifespan of nuclear power reactors offers a great alternative for countries that lack the financial means to construct new reactors. Additionally, as many reactors in commercial operation today were constructed with an average lifespan of 20-40 years, they require lifespan extentions. For instance, the average age of operating reactors in the USA was close to 42 years in 2022 (Figure 16) with the oldest being the Nine Mile Point Unit 1 in New York, which entered commercial service in December 1969l[152]. Currently, 88 of the 94 reactors have received approval for their first 20-year extension, with utilities looking into the possibility of applying for an additional 20 years of service[153]. This development underscores Washington's commitment to maintaining its leading position in nuclear-electric power generation.

The fleet of nuclear reactors in EU countries is also quite old, with an average age of slightly over 38 years. As of 2024, 88 of the 100 reactors in the Union are older than 31 years[154]. However, as mentioned in Chapter 5, many European countries, including Belgium and Spain, have decided to prolong the commercial operation of their reactors.

On the opposite side, China has the newest nuclear fleet in the world, with a mean age of approximately 9 years in 2022. India had the second youngest fleet with a mean age of 24 years. Therefore, extending the lifespan of their reactors is not considered by the government officials yet.

[152] "Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)." n.d. Accessed June 14, 2025. https://www.eia.gov/tools/faqs/faq.php?id.

[153] "What's the Lifespan for a Nuclear Reactor? Much Longer Than You Might Think." n.d. Energy.Gov. https://www.energy.gov/ne/articles/whats-lifespan-nuclear-reactor-much-longer-you-might-think.

[154] Statista "Nuclear Reactors Mean Age in the European Union 1970-2024." October 7, 2024. Accessed June 14, 2025. https://www.statista.com/statistics/1352921/mean-age-of-nuclear-power-reactors-eu.

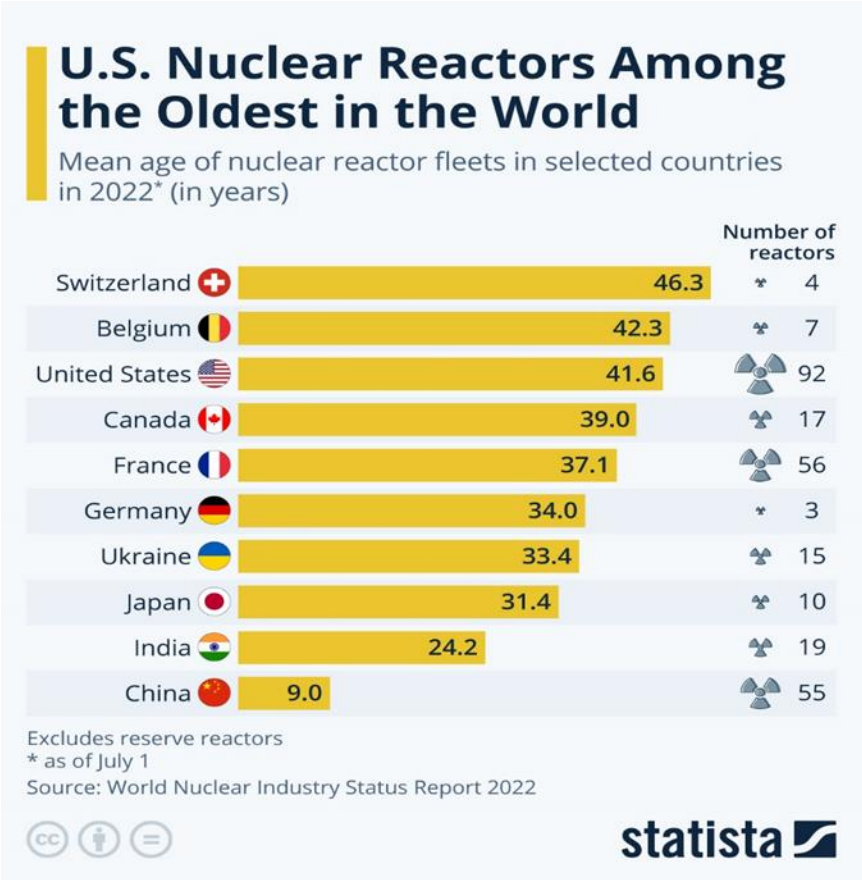

Figure 16: Mean age of nuclear reactors fleets in selected countries in 2022

Source: Statista (2022) U.S. Nuclear Reactors Among the Oldest in the World, https://www.statista.com/chart/28805/mean-age-of-nuclear-reactor-fleets-in-selected-countries/

To conclude, whether countries decide or not to expand their fleet will have a direct impact on the global production of nuclear power and consequently their ability to become key nuclear players. Washington has already moved in this direction, while Europe continues to make progress as well. Conversely, China's and India's fleets are relatively new, and therefore the matter does not apply to them.

7.4 Conclusions

By taking into consideration the share of nuclear power in their electricity mix, it appears that France and Slovakia already use nuclear power as primary fuel. Hungary, Finland and Belgium, are also covering an important part of their energy mix with nuclear power.

On the other hand, despite the USA, China, and Russia generating the largest amount of electricity from nuclear power, the share of nuclear electricity production as a percentage of their energy mix is rather small, especially in China. However, this situation may change a little, the three nations are planning to construct new nuclear reactors.

Finally, by comparing Beijing's and Moscow's nuclear exports, we can formulate several hypotheses regarding which of the two countries will prevail in this sector. Some may argue that Beijing is likely to surpass Moscow's current dominance due to the impact of the Ukraine war. However, others contend that the situation is challenging because of Russia's entrenched influence in the nuclear markets of its neighboring regions. An interesting aspect of this situation is that Europe will have a major influence on the outcome, as the EU heavily relies on uranium imports, which will soon be banned from Russia. It remains uncertain, however, whether China will be able to substitute, even partially, for Russian uranium imports given Beijing's geographical proximity to Moscow.

8. CHAPTER EIGHT: HOW WOULD THE NUCLEAR RENESAINCE AFFECT GEOPOLITICAL RELATIONS?

We have seen that Russia controls a substantial share of global uranium capacity. These sources are inaccessible to many Western utilities following the U.S. and EU ban on Russian uranium. Some Western states have boosted their uranium supply since 2022. For example, at least 10 mines have reopened in the USA, Australia, and Canada since 2022. However, global production is expected to remain below the requirements through 2030 and beyond.

This situation could be worse for the West. Kazakhstan produces 43% of the world's uranium and is considered an important alternative to Moscow's uranium imports. Most analysts, however, believe that an important portion of Kazakhstan's uranium will be directed toward Russia and China. Shipping materials in Western nation via the traditional route through St. Petersburg is also no longer viable because of the risk of sanctions. Alternative routes, such as those crossing the Caspian Sea through Azerbaijan and Georgia, are not only more expensive but also face constraints due to poor infrastructure.

On the other hand, Canada, as we saw, is an important uranium exporter to the EU. However, more collaborations need to be established. Otherwise, many Western countries, including countries of the block, could find themselves in a difficult situation.

Washington's effort to rewarm its estranged relationship with Moscow after President Trump's reelection might therefore benefit the US in the long run. After all, when it comes to the field of energy in general, Moscow and Washington have been discussing a possible restart of the Nord Stream pipelines. Russian Foreign Minister of Foreign Affairs Sergei Lavrov has said in this regard that *«it would be interesting if the USA could use their influence on Europeans»* to make them more accepting of Moscow's gas.[155]

Of course, a sudden rapid increase in cooperation is rather difficult, especially since the diplomatic relations between the two states had reached a record low prior to January.

[155] Jack, Victor. 2025. "Russia and US Discuss Restarting Nord Stream Pipelines, Kremlin Says." POLITICO, March 26, 2025. https://www.politico.eu/article/russia-united-states-nord-stream-gas-pipelines-sergey-lavrov/.

Nonetheless, the Kremlin views Trump's presidency with less hostility, setting the foundation for a new era of diplomatic contacts. After all, a 30-day energy ceasefire in Ukraine brokered by the Trump administration was supposed to be a groundbreaking development, as no such deal was made in the past. Specifically, many viewed the deal as a promising factor to alleviate the extreme tensions between the US and Moscow. However, it is important to note that the deal was often violated, primarily by the Russians, and therefore, it had very little impact on the betterment of their actual relations.

Nonetheless providing that cease fire or even a peace agreement in Ukraine is reached following US mediation, major changes will happen geopolitically. We can expect that Washington will lift at least some of the sanctions imposed on various fields. Given the positive attitude towards the Nord Stream pipelines, it is possible that among these fields there will be the energy one. Providing such a development occurs, a uranium deal between the two superpowers is hardly unimaginable.

On the other hand, Europe continues to proclaim its staunch support for Ukraine unlike American president Trump, who demanded that Ukraine pay $100 billion in exchange for a minerals-for-aid agreement[156]. There has also been no effort from the EU to reengage with Russia. Consequently, it is likely that the relationship between Moscow and Brussels will remain strained for a considerable time, possibly even after a peace-deal is reached. This is particularly evident in light of Russian Foreign Affairs Minister Sergey Lavrov's blunt statement in February 2025, asserting that Europe has no role in the peace negotiations between Russia and Ukraine[157]. This does not mean that EU-Russian relations cannot eventually recover. However, this is almost certainly not going to happen before the war in Ukraine ends, and it would be challenging if a peace deal favors Moscow while neglecting Kyiv's needs.

[156] 'US Softens Calls for Ukraine to Pay Back Aid in Minerals Deal Talks – Bloomberg, April 16, 2025, By Volodymyr Verbianyi and Alberto Nardelli n.d. Accessed date June 16, 2025. https://www.bloomberg.com/news/articles/2025-04-16/us-softens-calls-for-ukraine-to-pay-back-aid-in-minerals-deal-talks

[157] Tass. 2025. "Europe Not Interested in Ukraine Peace, Has No Place at Negotiating Table — Lavrov." TASS, February 17, 2025. https://tass.com/politics/1914447.

8.1 Iran-USA

While the NPT establishes the right of all member states to exploit nuclear power for peaceful purposes, the prospect of an Iranian nuclear program is quite alarming to some countries, including the US.

While discussing the history of nuclear power, we saw that Washington withdrew from the JCPOA in 2018 due to fears of a potential proliferation of nuclear weapons, despite Tehran being a member of the NPT since 1971. Two years later, the IAEA also expressed concerns over Iran's ability and will to comply with its safeguards, particularly regarding access to certain nuclear sites[158].

On the other hand, Iran has declared on several occasions that it does not wish to acquire nuclear weapons. Therefore, it views IAEA's concerns with hostility and has threatened to withdraw from the Treaty of Non-Proliferation of Nuclear Weapons if its right to exploit nuclear power is not properly granted. Naturally, these threats exacerbate the situation and heighten doubts about Tehran's genuine intentions behind uranium enrichment. After all, the IAEA Director General warned the international community that Iran has enough uranium enriched to near-weapons-grade levels to make "several" nuclear bombs if it chooses to do so [159].

Tensions between Iran and the US have risen spectacularly after President Trump's reelection. Iran has accelerated its production of near weapons-grade uranium, which obviously revived the American fears of nuclear proliferation. US National Security Council spokesperson Brian Hughes said in Feb 2025 that *«President Trump has put the Iran regime on notice by reimposing maximum pressure and is committed to ensuring the regime never gets a nuclear weapon»,* while

[158] International Atomic Energy Agency. 2020. "IAEA Board Calls on Iran to Fully Implement Its Safeguards Obligations." IAEA, June 23, 2020. https://www.iaea.org/newscenter/news/iaea-board-calls-on-iran-to-fully-implement-its-safeguards-obligations.

[159] "Iran Accelerates Production of Near Weapons-grade Uranium, IAEA Says, as Tensions With US Ratchet up | AP News." 2025. AP News. February 26, 2025. Accessed June 14, 2025. https://apnews.com/article/iran-nuclear-iaea-weapons-grade-uranium-trump-0b11a99a7364f9a43e1c83b220114d45.

adding that the American president *«is open to talks with Iran to come to an agreement that fully addresses the outstanding issues between our two countries.»*

Iranian president Masoud Pezeshkian declared that his country would not directly negotiate its nuclear program with the US for as long as Washington continues to impose maximum pressure on Tehran. As a response, the American president went as far as to threaten Iranians with *«bombing the likes of which they have never seen before»*[160], if they refuse to make a US-approved nuclear deal. Responding to this threat, Iran's Supreme Leader Ayatollah Ali Khamenei said that the Americans *«would receive a strong blow»* [161] should they act against Tehran.

It was not until recently that the two parties decided to seriously engage in negotiations with Oman's mediation regarding the Iranian nuclear deal. It was not until recently that the two parties decided to seriously engage in negotiations with Oman's mediation regarding the Iranian nuclear deal. Talks are still ongoing, but predicting their outcome is difficult, particularly considering the recent alarming attacks by Israel on Iran.

On the one hand, it is only reasonable for both parties to compromise. A carefully structured agreement over Tehran's nuclear program could alleviate tensions by contributing to Iran reducing its production of near weapons-grade uranium.

On the other hand, one must not override the geopolitical crisis in the Middle East. The animosity between Israel and Iran has reached an unprecedented level. Tel Aviv is also currently engaged in war with Hamas in Gaza while also fighting Hezbollah in Lebanon. Tehran, however, supports both Hamas and Hezbollah. Therefore, Iran would benefit from a more lenient nuclear deal that would allow Tehran to clandestinely construct nuclear weapons and later transport them to its allies. After all, Iranian Foreign Minister Abbas Araqchi has stated that his country's right to uranium enrichment is «non-negotiable»[162].

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[160] 'Trump threatens bombing if Iran does not make nuclear deal' Doina Chiacu and David Ljunggren- Reuters March 31, 2025. https://www.reuters.com/world/trump-says-there-will-be-bombing-if-iran-does-not-make-nuclear-deal-2025-03-30/

[161] 'Iran will deliver 'strong blow' against US if it attacks, Khamenei says -Reuters', March 31, 2025.

https://www.reuters.com/world/middle-east/iran-supreme-leader-khamenei-rebuffs-trump-threat-over-nuclear-deal-2025-03-31/

[162] "Iran Says Its Right to Uranium Enrichment Is Non-negotiable." 2025. The Jerusalem Post | JPost.Com. April 16, 2025. Accessed June 15, 2025. https://www.jpost.com/breaking-news/article-850293.

8.2 Iran-Europe

Much like the US, the EU has often expressed concerns over Iran potentially acquiring nuclear weapons. The JCPOA, however, partially curbed those fears, as it established the basis for a peaceful use of nuclear power. On 31 July 2015, only 11 days after the UN Security Council approved Tehran's nuclear agreement, Brussels adopted all essential legal acts to lift the nuclear-related economic and financial sanctions against Iran. The EU's trust in the 2015 Iranian nuclear deal is also proven by the fact that the EU has been leading diplomatic talks to negotiate Washington's return to the JCPOA since April 2021. Although this was not achieved, it shows how the bloc was willing to support Iran's claim for the civilian uses of nuclear power.

Nonetheless, Teheran's stance during the ongoing wars in the Middle East and the deterioration of US-Iranian relations have alarmed the EU regarding Iran's true intentions behind the much-desired nuclear program. Suspicion against Tehran has spread among European leaders, with French Minister of Foreign Affairs Jean-Noel Barrot declaring in April 2025 that France, along with Germany and Britain, will not hesitate to reimpose UN sanctions on Iran unless a new nuclear deal emerges before the previous one expires in October 2025[163]. Tehran denounced these «threats, » according to news agency ISNA, stating that it is «completely unacceptable» for France to blackmail Iran in such a way.

However, despite the aggravating tension, the three western countries (France, Britain, and Germany, also known as E3) have decided to continue the dialogue with Tehran. A prominent example of E3's intention to engage in deep conversation with Tehran is a talk that was to take place between the two parties on May 2nd, 2025, in Rome[164]. Though these discussions were cancelled along with the American-Iranian negotiations that were scheduled for the following

[163] Reuters. 2025. "France Won't Hesitate to Restore UN Sanctions on Iran if No Deal, Says Foreign Minister." US News & World Report. April 29, 2025. Accessed June 15, 2025. https://www.usnews.com/news/world/articles/2025-04-29/france-wont-hesitate-to-restore-un-sanctions-on-iran-if-no-deal-says-foreign-minister.

[164] Reuters, 2025b. "Iran to Meet 3 European Powers Ahead of Next Nuclear Talks With US," April 30, 2025. Accessed June 15, 2025. https://www.reuters.com/world/iran-uk-france-germany-hold-nuclear-talks-friday-2025-04-30/.

day, they surely represented the will of the three Western countries to keep an open dialogue with Iran regarding its nuclear program.

8.3 Iran-Russia

Russia and Iran have improved their diplomatic relations after the war in Ukraine forced many Western governments to cut ties with the Kremlin. As a result, Moscow had no choice but to enhance collaborations with non-Western nations such as Iran, China, and even North Korea. Iran and North Korea, in particular, are considered crucial allies to Russia, as they have been providing Moscow with military support to continue the war, according to the international community. Consequently, it is only fair for Russia to endorse the Iranian claim for a peaceful nuclear program.

On the other hand, the Kremlin has urged Washington and Tehran to initiate direct discussions, despite Tehran refusing to do so. This is because Moscow sees a direct dialogue between the two parties as more suitable to ensure a nuclear agreement. For Russia, an Iranian nuclear deal could be of paramount importance, especially from an economic perspective. Provided that Tehran, a close ally of Moscow, uses nuclear power for peaceful reasons, the latter will be able to export uranium and other dual items to Iran. The outcome would be exceptionally good news for Russia, whose volume and value of exports have decreased due to Western sanctions.

8.4 Iran-Israel

Israel and Iran have been enemies since before the Gaza and Lebanon wars because Iran backs Hamas, Hezbollah, and the Houthis. However, the relationship between the two countries is now on the brink of war, with both exchanging aircraft attacks amidst the disastrous turmoil in the Middle East.[165].

It is particularly alarming that in June 2025, Israel targeted the Natanz nuclear facility, military bases, and various other sites in Iran, resulting in the assassination of three of Iran's top military leaders, along with numerous other senior military officials and several nuclear scientists[166]. It is important to mention that this incident happened despite the ongoing negotiations between Tehran and Washington. This development is bound to hinder any progress severely in conversations regarding a peaceful nuclear program and will at the very least reinforce Iran's strong opposition against quitting uranium enrichment.

Therefore, it is safe to assume that unless a ceasefire is achieved as soon as possible, negotiations concerning Tehran's nuclear program will plummet and another full-scale war will occur in the Middle East. If we also consider that nuclear facilities have been targeted, and will probably continue to be targeted, the results of this war could be extremely problematic.

8.5 Europe-China

In Chapter 7, we mentioned China's growing interest in becoming the greatest nuclear reactor supplier. Despite its continuous efforts, however, Beijing has not yet shaken Russia from its dominant position in the global market.[167] The EU's plans to phase out Russian energy imports could prove critical in reversing the status quo. However, to determine whether such a

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[165] Al Jazeera. 2025. "Iran Strikes Israel With New Missile, Drone Attack; Israel Bombs Tehran." Al Jazeera, June 15, 2025. https://www.aljazeera.com/news/2025/6/14/iranian-state-media-says-new-missile-drone-attack-launched-against-israel.

[166]Byman, Daniel. 2025. "What to Know About the Israeli Strike on Iran." In Center for Strategic & International Studies. https://www.csis.org/analysis/what-know-about-israeli-strike-iran.

[167] Li, Aitong, Yahan Liu, and Zongyao Yu. 2023. "China's Nuclear Exports: Understanding the Dynamics Between Domestic Governance Reforms and International Market Competition." Energy Research & Social Science 103 (August): 103230. https://doi.org/10.1016/j.erss.2023.103230.

development could truly be possible in the long run, we shall examine some of the recent actions concerning the enhancement of the EU-China energy cooperation.

As a third of the final energy consumption worldwide comes from the EU and China, their cooperation unsurprisingly aims to support the goals of the green transition. More specifically, every year since 1994, Brussels' and Beijing's officials have been engaging in a dialogue that centres around energy efficiency, RES, energy market reformation, and innovation. The dialogue between the two parties was deepened by the 2019 joint statement on the implementation of EU-China cooperation.

Up until 2022, Brussels-China relations were encouraged as both saw a significant trading partner in each other. Nonetheless, tension was created after Russia invaded Ukraine, as China refused to cut ties with Moscow, thus making the EU quite sceptical towards Beijing. The bilateral dialogue continued, however, and three joint reports on power market reforms, innovative energy solutions, and energy efficiency were presented during this time.

Moreover, the platform for EU-China energy cooperation, funded by the EU Partnership Instrument and jointly steered by the Commission's Directorate-General for Energy and the Chinese National Energy Administration, delivers on the specific objectives of EU-China energy cooperation. The platform also creates opportunities for political and policy exchange as well as new business prospects for innovative companies in the energy sector.

Furthermore, the EU-China partnership on urbanization touches upon energy matters as well. After all, it promotes energy-efficient buildings, technological innovation, and a broader use of renewable energy in urban areas.[168]

Taking this information into account, we can infer that energy cooperation in general has been cultivated between the two parties. Steps, however, have been made in the nuclear power sector as well. For instance, by 2016, Brussels and Beijing had successfully implemented the first joint project aimed at enhancing the nuclear safety regulatory framework in the world's second-largest

[168] China, European Commission, n.d. https://energy.ec.europa.eu/topics/international-cooperation/key-partner-countries-and-regions/china_en

economy. The project, whose worth was estimated at €2 million, was financed through the EU's Instrument for Nuclear Safety Cooperation[169].

The previous paragraph suggests that Brussels was concerned about Beijing's commitment to civilian nuclear power use. After all, despite China's nuclear fleet being relatively new, the country had been an NWS since 1964. Therefore, it was only fair for the EU to strengthen Beijing's nuclear safety regulations.

China imports European reactors or parts of them every year as part of the nuclear trade between the two parties. For instance, in 2023, Paris exported $194 million worth of nuclear reactors to China[170], establishing Beijing as its largest importer and the greatest source of revenue in this sector. Therefore, it is advantageous for Paris to maintain its nuclear reactor exports to China, even though these have seen a slight decline since 2020.

On the other hand, China is planning to export 30 nuclear reactors to the countries participating in the Belt and Road Initiative, as we saw prior. Among these countries are several EU and non-EU nations, including but not limited to Bulgaria, Romania, Serbia, Hungary, and Turkey, all of which have expressed interest in developing or strengthening their nuclear fleet. If this development is achieved, it would enhance the role of China as a nuclear exporter in the broader region of Europe.

Nonetheless, since the controversial Beijing-Moscow relationship has made some European nations quite suspicious towards China, the purpose of BRI would inevitably be questioned as well. Among the countries that have distanced themselves from the initiative is Estonia, which simultaneously has expressed an interest in acquiring a civilian nuclear power program. Therefore, Beijing's undisrupted diplomatic contact with Moscow could contribute to Tallinn refusing to buy Chinese nuclear reactors or even quitting the BRI altogether. Other countries, however, like Serbia, which has closer ties to Russia, seem unbothered by Beijing's stance and

[169] "EU Supports Enhancement and Strengthening of the Nuclear Safety Regulatory Framework in China." n.d. EEAS. https://www.eeas.europa.eu/node/15442_fr.

[170] "Nuclear Reactors in France Trade | the Observatory of Economic Complexity." n.d. The Observatory of Economic Complexity. Accessed May 26, 2025. https://oec.world/en/profile/bilateral-product/nuclear-reactors/reporter/fra.

view this initiative rather fondly. Consequently, they could be willing to import reactors from both Russia and China.

In summary, we cannot expect all European countries to welcome China's dominance into the nuclear export market. Depending on their histories, economic interests, political beliefs, and traditional alliances, both EU and non-EU members will have different approaches toward the world's largest economy. Nonetheless, it is important to underline that the prospect of nuclear cooperation between European countries and Beijing remains a viable option. However, the extent of this cooperation will be determined by each government's officials.

8.6 Conclusions

Russia controls a significant share of global uranium capacity, but many Western utilities are unable to access these sources due to the U.S. and EU ban on Russian uranium, which increases the pressure for countries to find an alternative. Washington's effort to rewarm its estranged relationship with Moscow after President Trump's re-election might benefit the US in the long run.

The Iranian nuclear deal has been a topic of concern for some countries, including the US, due to fears of potential proliferation of nuclear weapons. Washington withdrew from the Joint Comprehensive Plan on Atomic Energy (JCPOA) in 2018 due to these fears. Iran, however, has stated that it does not wish to acquire nuclear weapons and has threatened to withdraw from the Treaty on the Non-Proliferation of Nuclear Weapons if its right to exploit nuclear power is not properly granted.

Tensions between Iran and the US have increased since President Trump's reelection, as Iran has accelerated its production of near weapons-grade uranium. The US National Security Council has stated that President Trump is committed to ensuring the Iranian regime never gets a nuclear weapon and is open to talks with Iran to come to an agreement. The geopolitical crisis in the Middle East, particularly the ongoing conflict between Israel and Hamas, Hezbollah, and possibly a war with Iran, has aggravated concerns about Iran's true intentions behind the nuclear program.

The 2015 JCPOA nuclear deal partially alleviated the EU's fears regarding nuclear proliferation stemming from Iran's acquisition of a nuclear program. Therefore, it has been leading diplomatic talks to negotiate Washington's return to the JCPOA since April 2021. However, there has been no significant progress so far.

Finally, since 1994, the EU and China have been engaging in dialogues focused on energy efficiency, renewable energy, market reformation, and innovation. The EU-China platform for energy cooperation, funded by the EU Partnership Instrument, supports these objectives and creates opportunities for political and policy exchange. European nuclear reactors, especially French ones, are also imported to China annually. Furthermore, Beijing plans to export 30 nuclear reactors to countries participating in the Belt and Road Initiative (BRI), including Bulgaria, Romania, Serbia, Hungary, and Turkey. However, the controversial Beijing-Moscow relationship has made some European nations suspicious of China, leading to distance from the initiative. Some countries, like Estonia, may be willing to import reactors from both Russia and China.

9. CHAPTER NINE: COULD AN EXPANSION OF NUCLEAR ENERGY LEAD TO CONFLICT?

Over the years, many political theories have tried to analyze the importance of nuclear power and whether it is linked or not to nuclear proliferation. Though plenty of theories have emerged and have contributed greatly to our understanding of the world, the major ones are Realism, Liberalism and Constructivism.

9.1 Realists' approach

Those who fear that an expansion in the use of nuclear power would lead to nuclear war are often supporters of political realism and therefore associate nuclear power with the proliferation of nuclear weapons, despite the existence of the NPT.

More specifically, according to scholars of political realism, states, which are egocentric and prone to violence, are the most important actors in the anarchic international system. Therefore, it is the responsibility of the states to ensure their survival. In this regard, advanced military capacity is considered crucial for countries' self-preservation. This is because by having a superior military capacity, they can fight an attacking state or invade another that is perceived as threatening, thus eliminating their enemies and simultaneously increasing their power. Consequently, every step a state takes to improve its army or war-related technology is perceived by others as threatening behavior, thus leading to a security dilemma. The security dilemma is of paramount importance in understanding how and why nuclear power is often linked with fears over potential global arms races through the lens of political realism. In other words, states fear other states, especially those possessing the means to harm them. Therefore, it is believed that a state's survival depends on its ability to be unbeatable, by possessing the greatest possible military technology. In the real world, nuclear weapons are the most powerful military technology.

Consequently, it is only fair that each state would want to exploit the dual nature of nuclear exports and develop its own nuclear weapons. This scenario could be achieved if NNWS joined NPT to gain access to nuclear technology and then exited once they gathered the means to enrich uranium. Such was the case with North Korea, which was initially a part of the NPT but left in 2003, citing safety concerns. Ever since, Pyongyang has conducted six nuclear weapon tests and issued numerous threats of war in the name of national security, increasing the tensions on the Korean Peninsula.

Realists also examine NPT with the lens of "cartel" theory, which views the treaty as a way for the five NWSs to maintain their nuclear oligopoly and preeminence.[171] Initially, the nuclear powers viewed the proliferation of nuclear weapons among their allies as a strategy to enhance their own influence against opposing forces. Later on, though, they realized that the proliferation of nuclear weapons would actually make it harder for them to maintain control over these allies. This shift occurred because allies could rely on their own nuclear capabilities as a substitute for the security assurances provided by the nuclear powers, thereby gaining greater autonomy.[172] Therefore, the NWSs collectively bribed and coerced the NNWSs to comply with the principles of nonproliferation through a combination of multilateral and bilateral agreements.[173] This theory suggests that the NPT was created by the nuclear-armed states working together to prevent the spread of nuclear weapons, and it now helps manage what non-nuclear states expect in return for following the rules and strengthens the oversight of those that do not comply.

The approach of political realism seems rather reasonable, especially if applied to the current turbulent geopolitical circumstances. The ongoing war between Russia, a nuclear superpower, and Ukraine, which is heavily supported by NATO, has led both parties to amplify their weaponry production. In this regard, the international community has expressed concern over Moscow's nuclear intentions, especially since former Russian president Dmitri Medvedev has stated many times that a nuclear war between Russia and the USA is very close.

[171] Andrew J. Coe and Jane Vaynman, "Collusion and the Nuclear Nonproliferation Regime," Journal of Politics 77, no. 4 (October 2015): 983–97, and Daniel Verdier, "Multilateralism, Bilateralism, and Exclusion in the Nuclear Proliferation Regime," International Organization 62, no. 3 (2008): 439–76

[172] Coe and Vaynman, 983–84

[173] Verdier, "Multilateralism, Bilateralism, and Exclusion," 439–41.

Nonetheless, some may argue that even though the theory of political realism makes valid points, it is somewhat outdated and pessimistic. After all, states have cooperated numerous times over the years, rather than constantly competing and fighting each other. This cooperation can be seen in international organizations and treaties (including the NPT) that are in force today.

9.2 Liberalists' approach

Liberalism is a school of thought in international relations theory that is based on three ideas: that power politics is not the only possible outcome of international relations, that countries should work together for their own good, and that international organizations and non-governmental actors can help shape state preferences and policy choices.[174]

This theoretical framework highlights three elements that promote increased cooperation and less conflict among nations:

- International institutions that offer a platform for the peaceful resolution of issues.
- International trade fosters economic interdependence among nations, hence reducing the likelihood of conflict.
- Spread Democracy, which assumes that no wars occur between democratic nations

Liberals assert that international institutions are crucial in fostering cooperation among states through interdependence.[175] States interact in various ways, through economic, financial, and cultural means. Therefore, it is in their best interest to avoid conflicts that could reduce the benefits of these interactions.

Liberals also argue that international diplomacy can be a very effective way to get states to interact with each other honestly and support nonviolent solutions to problems. In this regard, wars are undesirable, as they diminish the benefits that each state can obtain through

[174] Shiraev, Eric B. (2014). International Relations. New York: Oxford University Presses. p. 78.

[175] Shiraev, Eric B., and Vladislav M. Zubok. 2014. International Relations. New York, NY:Oxford University Press.

cooperation. In other words, liberals believe that nations can work together to maximize prosperity and minimize conflict.

Despite being more optimistic and inclusive of international institutions and cooperation, this theory also disregards many aspects of state-to-state interaction. It is true that cooperation enhances economic benefits for the population of nations evolved, especially if this cooperation is achieved by democratic nations. However, it fails to explain why many of them proceed to engage in warfare in the first place. After all, if we consider the turbulence worldwide, the liberals' approach seems more utopian than pragmatic.

9.3 Constructivists' approach

According to scholars of constructivism, a norm is "a standard of appropriate behavior for actors with a given identity"[176] Such scholars argue that states shift from following "a logic of consequences" to following "a logic of appropriateness" as norms diffuse among them and alter their belief systems.[177]

In the field of nuclear politics, the prominent norm is nuclear non-proliferation[178] as seen in the case of NPT. Thus, when a state signs the NPT, its membership does not solely involve material terms but also means that it must abide by the associated ideas.[179]

Over the years, the international community has taken several initiatives towards the non-proliferation goal besides or in support of the NPT, such as the World Association of Nuclear Operators, the NSG, and the IAEA Convention on Nuclear Safety. These efforts could explain why only a few states have constructed nuclear weapons during past decades.

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176 Martha Finnemore and Kathryn Sikkink, "International Norm Dynamics and Political Change," International Organization 52, no. 4 (1998): 891

177 Jeffrey T. Checkel, "International Institutions and Socialization in Europe: Introduction and Framework," International Organization 59, no. 4 (2005): 804.

178 Rublee, Nonproliferation Norms, 39.

179 Etel Solingen, "The Political Economy of Nuclear Restraint," International Security 19, no. 2 (Fall 1994): 140E

Similarly, when it comes to NWS, norms indicate that they refrain from hostilities that could result in a nuclear war. Indeed, no direct conflict between nuclear-weapon states has ever been recorded, except for the brief yet severe escalation of hostilities between India and Pakistan, which had nothing to do with nuclear power or weapons. Even the USA and Russia, whose diplomatic relations have reached a record low after Moscow's invasion of Ukraine, have not engaged in war. Despite Moscow's threats and Washington's military support for Kiev, both parties seem to estimate that a direct conflict, which would also require that NATO be involved, would be absolutely devastating.

To conclude, it is true that most states follow the norms concerning nuclear weapons and conflicts and are eager to participate in treaties against nuclear proliferation. This is because they either fear stigmatization or simply because they do believe in abstaining from actions that could result in negative consequences.

Constructivists' approach addresses a lot of the inconsistencies of the previous ones yet still fails to encapsulate the reason why some countries leave the NPT, despite knowing that such actions will stigmatize them. After all, norms have been crucial for the ratification of the Non-Proliferation Treaty by so many states. On the other hand, constructivist theory fails to capture the need for self-preservation that compels countries to act in ways that may be deemed inappropriate if such actions are perceived as essential for their survival, particularly during periods of geopolitical turbulence.

Furthermore, authoritarian governments often perceive agreements such as the NPT with suspicion. Therefore, even if they are coerced by some norms into accepting their terms and conditions, they are more likely to withdraw due to safety concerns. Such concerns escalate during times of crisis, when even democratic states tend to be more skeptical about the actions of other countries, especially if there is a lurking animosity between their external policies.

In this regard, game theory can help us understand why some countries behave contrary to well-established norms, which in our case involve the ones concerning nuclear power and proliferation, and whether such actions could lead to a potential conflict.

9.4 Game theory

We assume that all states have access to or actively use nuclear power.

During times of peace, the principles of the Non-Proliferation Treaty are eagerly followed by its member states, especially democratic states. However, given that multiple wars and conflicts take place worldwide, it is possible that many signatories will feel unease. If these concerns are combined with fears regarding nuclear proliferation because of expanding the use of nuclear power worldwide, a security dilemma will likely occur. Consequently, many countries will choose to increase their military expenses to prepare themselves against an imminent attack.

Under these circumstances, each state is presented with two choices. A) To keep following the rules of NPT and refrain from constructing nuclear weapons or B) To breach NPT and create nuclear weapons.

The table below helps us understand the impact of each choice taken by State 1 on State 2 and vice versa at the non-cooperative game of prisoner's dilemma:

State 2

	Abstain from creating nuclear weapons	Create nuclear weapons
Abstain from creating nuclear weapons	5,5	1,6
Create nuclear weapons	6,1	3,3

State 1

If both states choose to remain compliant with the principles of NPT, they will receive the greatest payoff, meaning that (Abstain from creating nuclear weapons, abstain from creating nuclear weapons) is the Pareto efficient outcome. That can only happen, however, in a world where sincere communication and trust exist between players. Unfortunately, this kind of interaction is rather rare in the real world, as both players have the incentive to cheat.

In fact, if State 1 chooses not to construct nuclear weapons and State 2 does, then State 1 would be unprepared against the possibility of State 2 attacking State 1 with these weapons. Under these circumstances, the best strategy for both players is to construct nuclear weapons, meaning that (Construct nuclear weapons, construct nuclear weapons) is the Nash equilibrium of the game. By choosing this strategy, each state would be prepared to fight back if the other attacked. Such development, however, creates a stressful situation for both parties, forcing them to be constantly on high alert for potential war, which is why the Nash Equilibrium is not the Pareto efficient outcome.

The Prisoner's Dilemma can be solved either through repeated interactions, which allow cooperation to emerge over time, or through enforceable agreements, credible threats or promises that alter the payoff structure to ensure compliance.

Such examples from the real world are weapon control, either by NPT or other nonproliferation initiatives, that allowed countries to reward cooperation and stigmatize the ones who failed or chose not to comply[180]. However, despite all the efforts made, there are still disarmament issues when it comes to NWS, as none of them have explicitly abandoned nuclear weapons.

Nonetheless, despite what countries fear, a nuclear war is not guaranteed if several countries acquire nuclear weapons. This is because there are no potential benefits from such conflict for the parties involved. What is dangerous, on the other hand, is that in a state of panic and fear, one player could do something that could be perceived as threatening behavior by the other. This could very likely trigger a nuclear attack as a response to this «threatening behavior,» thus dragging both parties into a highly disastrous conflict.

It is important to keep in mind, however, that a war between two NWSs could also occur due to reasons completely irrelevant to nuclear proliferation. The recent escalation of hostilities between India and Pakistan, for example, had nothing to do with nuclear weapons but rather with a massacre that took place in the controversial region of Kashmir, the apple of discord for the two countries.

[180] Scheve, Tom. 2023. "How Game Theory Works." HowStuffWorks. August 18, 2023. Accessed June 16, 2025. https://science.howstuffworks.com/game-theory2.htm.

Of course, the fact that both India and Pakistan are NWS increases international concerns about the consequences of a potential full-scale nuclear war between New Delhi and Islamabad. On the other hand, the dangers associated with nuclear proliferation have preoccupied government officials for so long that both countries understand the importance of deescalating the situation before it is too late.

9.5 Conclusion

Over the years many schools of thought have tried to interpret aspects of international relations, including the possible dangers lurking behind the expansion of nuclear power.

Realists tend to view the international system as a hostile place, where if a state wants to expand its power, it must do so against another. Cooperation is impossible, and countries are bound to fight each other until the most powerful prevails. Under these circumstances, countries will exploit any loophole presented by their access to nuclear power and will create nuclear weapons to prevail.

Liberalists, on the other hand, believe that there are many ways to achieve cooperation, such as international institutions and trade, which diminish the attractiveness of a conquest war. In this regard, by extending the use of nuclear power, a nuclear conflict is unlikely to happen due to countries acknowledging the detrimental effect of nuclear power. As a result, peaceful means of using nuclear power are promoted, and countries (both NWS and NNWS) are willing to comply with the rules of the NPT.

Lastly, constructivists believe that countries behave the way they behave depending on what is considered acceptable or not. As a result, even if the use of nuclear power is expanded worldwide, nuclear proliferation is not guaranteed, as international norms are against it.

All these theories make valid points, but they also present inconsistencies. Game theory attempts to give a more practical explanation regarding states' behavior, yet it still fails to give a definite answer concerning the relationship between nuclear power and conflict.

In general, since no total war has occurred between NWS (besides hostilities between India and Pakistan), it is safe to assume that even if proliferation happens due to a global expansion in the use of nuclear power, we can expect that countries will show rationality and avoid escalating existing conflicts, as the example of India and Pakistan indicates. On the other hand, if a series of countries choose to leave the NPT and acquire nuclear weapons, suspicion will arise, leading to spasmodic actions that could promote destabilization.

In conclusion, no theory or game can fully guarantee or disprove the compliance of NPT member states to peaceful means of nuclear power, especially during turbulent times. Nonetheless, we can assume that since the treaty has consisted of so many states for many years without severe repercussions, things will be unlikely to change if more countries decide to initiate nuclear programs.

10. CHAPTER TEN: RECAP AND CONCLUSIONS

Nuclear energy, discovered in Germany in 1938, is a form of energy produced through fission or fusion.

Since fission's discovery was historically placed during severely turbulent times, London and Washington were afraid that Berlin was creating an atomic bomb. Therefore, they decided to be the ones to create it first. As a result, the Manhattan Project, a secret research and development program between USA, London and Canada was born. The participants managed to create nuclear weapons, though by that time Germany was no longer a threat. In fact, it was Japan that was still presenting reversionistic tendencies. On August 6 and 9 1945, two bombs were dropped on Hiroshima and Nagasaki, killing an estimate of 100.000 people, forcing Japan's surrender. The devastating impact of the bombings led to the signature of the Atomic Energy Act in 1946 to prevent the spread of nuclear weapons. The restrictions were extremely strict and therefore it was immensely difficult to spread scientific know-how regarding nuclear.

Dwight Eisenhower's presidency, which began in 1953 emphasized the need for peaceful uses of nuclear technology, leading to amendments to the Atomic Energy Act, the creation of the International Atomic Energy Agency (IAEA), and the Treaty on the Non-Proliferation of nuclear weapons (NPT). The NPT, still in force today and signed by almost all nations, recognizes each state's right to use nuclear energy for civilian purposes and allows transferring nuclear material with IAEA approval.

The Nuclear Supplier Group (NSG) was formed in 1974 to enhance controls regarding nuclear material and technology exports. The US took a more cautious approach to nuclear cooperation with countries without nuclear weapons, forcing the rest of the NSG to adopt reforms made by Washington.

The Three Mile Island and Chernobyl disasters further fueled fears about nuclear energy safety. Also, the 2011 Fukushima nuclear accident caused many countries to reconsider nuclear investments, leading to discussions on alternative clean energy production and ambitions about expanding nuclear power.

However, discussions about nuclear power have resurfaced. After all, it offers significant benefits, while being a clean and safe form of energy for the environment. Its low operating costs reduce nuclear prices per kilowatt, making it attractive to consumers and investors. Nuclear power can also boost domestic economies by providing high-quality jobs and preventing skilled individuals from seeking employment elsewhere. However, it also faces challenges such as high capital costs, waste management issues, long construction times, and the general concerns about proliferation.

Capital costs vary by country. They are higher in mature markets like Europe and North America, and lower in the emerging industrial economies of Asia. Construction times are always delayed as well, with technical issues, shortages of qualified staff, supply-chain disruptions, stringent regulation, and voter pushbacks contributing to these delays. Nuclear waste and pollution also raise significant concerns, as disposal solutions are poor, and inadequate.

Fears regarding nuclear proliferation have also sky-rocketed, due to the ongoing global expansion of nuclear power usage. The International Atomic Energy Agency (IAEA) has implemented an Additional Protocol to ensure no undeclared nuclear materials or activities within affected states.

There are also concerns about the potential impact of nuclear accidents, since nuclear facilities are susceptible to earthquakes and tsunamis. Geopolitical factors, such as Russia's invasion of Ukraine and the seizure of the Zaporizhzhia nuclear power facility, exacerbate the likelihood of new nuclear accidents.

Small Modular Reactors (SMRs) could increase the share of nuclear power in the global energy mix during the green transition due to their safety characteristics and low power capacity, which makes them more flexible and affordable than larger reactors. They are considered eco-friendly and could contribute to achieving Net Zero Emissions by 2050 if investments in SMRs intensify.

Electrification is a key component of Green Transition, with around $1.1 trillion invested annually in low-emission electricity sources. Nuclear power plants generate around 22.8% of the total electricity produced in 2023, and carbon pricing is an economic incentive for decarbonization.

Heating is another crucial aspect of the Green Transition, with coal and natural gas producing 45% and 41% of global heat in 2021, accounting for 38% of energy-related CO_2 emissions. Nuclear power is considered a promising field for district heating, and countries like Bulgaria, Canada, China, the Czech Republic, Germany, Hungary, India, Japan, Kazakhstan, Russia, Slovakia, Sweden, Switzerland, and Ukraine have found it convenient to apply nuclear heat for district heating or industrial processes in addition to electricity generation.

Large tech companies like Amazon and Google have also shown a profound interest in nuclear technology. The financial support of massive established customers could help keep old nuclear power plants open, as many western countries are hoping to prolong the lifespan of their reactors. and promote new technologies.

About 30 states are considering, planning, or starting nuclear power programs, with around 60 nuclear reactors currently under construction worldwide. The global demand for hydrogen has increased due to energy transition, but building a reactor entails huge upfront costs, which decreases its attractiveness compared to renewable energy sources.

On the other hand, the nuclear industry faces significant threats from natural gas, renewable energy sources, and the public's perception of nuclear accidents. France and Slovakia have been successfully using nuclear power as primary fuel during energy transition, while the US, China, and Russia generate the largest amount of electricity from nuclear power. However, the share of nuclear electricity production in their energy mix is small, especially in Beijing.

China, Russia and the USA plan to construct new nuclear reactors to boost their fleets and increase consumption of nuclear power.

Russia controls an important share of global uranium capacity, but many western utilities are unable to access these sources due to the U.S. and EU ban on Russian uranium. Since global production is expected to remain below reactor requirements from now to 2030 and beyond. Western countries will be expected to face quite a predicament, unless collaborations are made with alternative suppliers. In this regard, Washington's effort to rekindle its estranged relationship with Moscow after President Trump's reelection might benefit the US in the long run.

Tensions between Iran and the US have risen since President Trump's reelection, as Iran has accelerated its production of near weapons-grade uranium.

The EU and US have expressed concerns over Iran's potential acquisition of nuclear weapons, but the 2015 JCPOA has partially mitigated European fears. In fact, the EU has been leading diplomatic talks to negotiate Washington's return in JCPOA since April 2021, while France, Britain, and Germany (E3) have decided to continue dialogue with Tehran.

The relationship between Russia and Iran has improved since the war in Ukraine. A peaceful Iranian nuclear deal is crucial for Russia, as it would allow Tehran to export uranium and other dual items to Iran.

China plans to export 30 nuclear reactors to countries participating in the Belt and Road Initiative (BRI), but the controversial Beijing-Moscow relationship has made some European nations suspicious of China. Nuclear cooperation is not out of the picture, but the extent depends on each Beijing's future stance.

Finally, by taking into account the main theories of international relations, we can understand some of the states' behaviors, but they fail to accurately predict whether cooperation or conflict shall occur, if the use of nuclear power expands. Game theory suggests a practical explanation on why some nations engage in warfare, even if a war will not benefit them in the long run.

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