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Research Article

Turkey's Nuclear Energy Ambitions: Past Efforts, Present Strategies, and Future Directions

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ABSTRACT

Nuclear power plants, popularized by the promise of decreasing dependency on foreign resources and providing supply security, meet 10% of the world's energy needs as of 2023. Having had this desire for a long time, Turkey wants to have a nuclear-installed power of 10,000 MW according to its energy production targets. In this context, Turkey seems close to realizing this de sire of more than half a century with its Akkuyu and Sinop Nuclear Power Plants. Yet, Turkey follows a different path compared to countries with a nuclear past and took its first concrete steps with an intergovernmental agreement signed with Russia. In this study, the main motivation pushing Turkey to this path, the country's technical capacity, and its strategy are evaluated. Besides that, the current and possible prospective hazards are indicated. In addition, the contribution of these plants to meet the electricity demand as well as reducing dependency on external resources and the current account deficit have been examined. Turkey's nuclear energy initiative's environmental, economic, and political dimensions have also been addressed, and its long-term strategic impacts have been analyzed. The study also details the potential impact of nuclear energy investments on Turkey's energy supply security. The study, which also includes a SWOT analysis, predicts that Turkey's intergovernmental agreement-based initiative will serve as an important reference for other future initiatives.

Keywords: *Akkuyu Nuclear Power Plant, Energy Policy, Nuclear Energy, Nuclear Energy in Turkey, Sinop Nuclear Power Plant.*

I. INTRODUCTION

Due to increasing population and technological advancements, energy demand continues to rise in developing countries. The intermittent nature of existing renewable energy sources such as solar and wind energy (Elibol & Dikmen, 2023), the high costs required for large-scale power generation, and the low availability to meet instantaneous demand appear to be disadvantages for these sources (Basit et al., 2020; Maradin, 2021). Therefore, hydrocarbon-based fossil fuels have always had a larger share in meeting the increasing demand than other primary energy sources. This leads to problems such as environmental pollution, high emissions and global warming. Herein, nuclear energy has a significant role on the table with its ability to help decarbonize the electricity supply. Nuclear power plants play a significant role in securing global pathway to net zero. The journey of atomic nuclei, which started with the first power plant opened in Russia in 1954, extends to the present day. Nuclear power plants, which are not only a scientific development but also closely related to world politics, met 10% of the world's

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electricity demand in 2023 and became the second largest source of low-emission (i.e. non-fossil) electricity after hydropower (Schneider & Froggatt, 2020).

The aim of this study is to reveal the reason for Turkey's desire to build a nuclear power plant, country's infrastructure and the chosen path to build it. Despite the global emphasis on nuclear energy, limited research has been conducted on the specific strategies and challenges faced by Turkey in its pursuit of nuclear energy. This study aims to fill this gap by providing a comprehensive evaluation of Turkey's nuclear energy strategy, its technical capacity, and potential risks. It will also be examined the country's failed attempts and the pros and cons of its new strategy. In this study, Turkey's energy outlook will be discussed in Section 2 and the history of nuclear energy in the world will be discussed in Section 3. Following this, in Section 4, the history of Turkey's attempts to establish nuclear power plants, the country's motivation, capacity and strategy in this field will be examined. In the same section, the impact of this investment on the cost of electricity and SWOT analysis of nuclear energy in Turkey will be discussed. In Section 5, the impacts of Turkey's approach will be discussed.

II. TURKEY'S ENERGY OUTLOOK

While Turkey exhibited an average economic growth trend of 4.8% between 2014 and 2023, the average increase in electricity consumption remained around 2.9% (SHURA, 2023). Although the relation between growth rate and electricity consumption is not always directly proportional, it is often an important indicator. In 2024, Turkey generated around 349 GWh of electricity. Of this amount, 35.2% was obtained from coal, 21.5% from hydroelectric power plants, 18.9% from natural gas, 10.5% from wind energy, 7.5% from solar energy, and the rest from other sources as it is seen in Figure 1 (*Türkiye Ministry of Energy*, 2025). As can be seen from the current situation, Turkey is a foreign-dependent country for energy, and dependence on imported fossil fuels poses a risk in terms of energy supply.

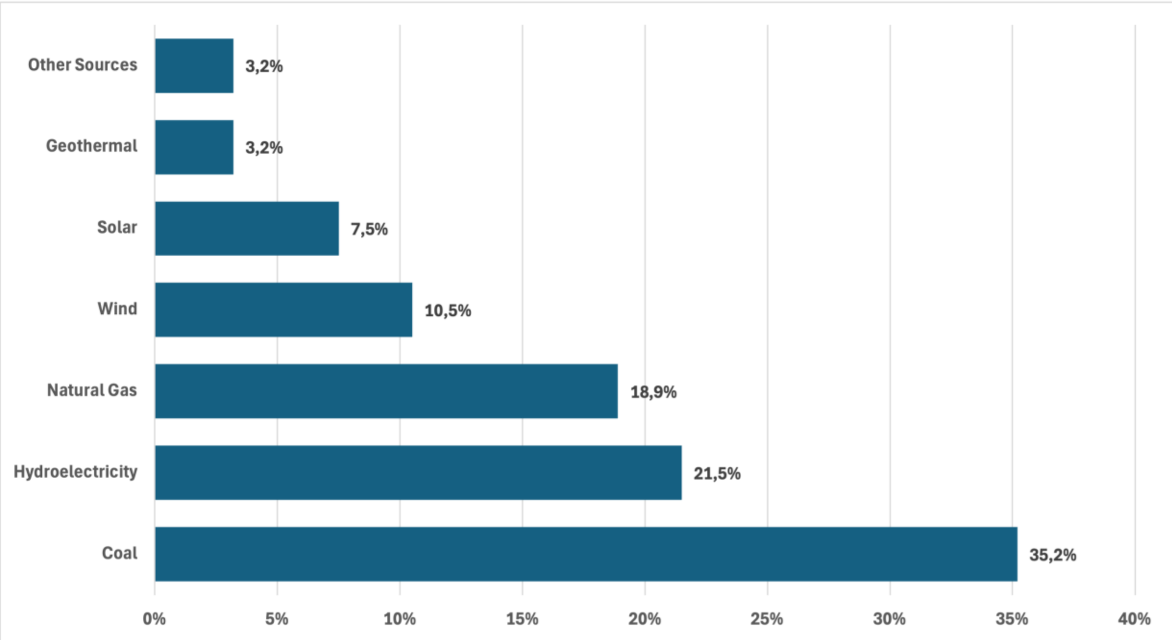

Figure 1. Distribution of Turkey's Production of Electricity in 2024 Based on Resources (*Türkiye Ministry of Energy*, 2025).

In 2022, Türkiye's reliance on imported fuels for generating electricity rose from 41% to 43%. This trend has persisted for the past four years, with no signs of improvement. The increase in import dependency can be attributed to the growing use of fossil fuels in electricity generation (Gümüş, 2024). Being a poor country in terms of fossil fuels such as oil, natural gas, and coal with high thermal value, the natural gas reserves discovery in the Black Sea offshore in 2020 is promising for Turkey (*BBC News Turkish*, 2023). According to the national targets, Turkey aims to supply 30% of the total electricity production from renewable energy sources and to commission a nuclear power plant with an installed capacity of 10,000 MW (Melikoglu, 2016).

III. NUCLEAR ENERGY OUTLOOK

A. Technology

Nuclear energy is the enormous amount of energy released from the disintegration (fission) of heavy atomic nuclei due to neutron capture and the merging (fusion) of light atomic nuclei at very high temperatures (WNA, 2024). This emerging energy is utilized in producing electricity through thermal processes in a nuclear power plant. Currently, nuclear power plants operate using a fission reaction mechanism. During nuclear fission, a neutron collides with a uranium atom used as fuel, causing the atom to split and releasing a significant amount of heat and radiation energy. The energy released during nuclear fission can be calculated using Einstein's mass-energy equivalence principle, given by the Equation 1:

$$E = \Delta m \cdot c^2 \quad (1)$$

where:

- E is the energy released (in joules),
- Δm is the change in mass (in kilograms), and
- c is the speed of light in a vacuum (3×10^8 meters per second).

When a uranium-235 nucleus undergoes fission, a small amount of mass is lost, which is then converted into a large amount of energy. If the mass defect (Δm) is approximately 0.1% of the original mass, the released energy can be substantial as stated in Eq. 2.

$$\begin{aligned} \Delta m &\approx 0.001 \times m_{U-2.55} \\ E &= 0.001 \times m_{U-2.35} \times (3 \times 10^8)^2 \end{aligned} \quad (2)$$

where $m_{U\ 235}$ is the mass of a uranium-235 nucleus (approximately 3.9×10^{-25} kg). Substituting the values, on Eq. 3 we get:

$$\begin{aligned} E &\approx 0.001 \times 3.9 \times 10^{-25} \times 9 \times 10^{16} \\ E &\approx 3.5 \times 10^{-11} \text{ joules per fission reaction} \end{aligned} \quad (3)$$

This heat energy is converted into steam from water and sent to a turbine, which then generates electricity through a generator to reach the end user. Nuclear energy is used not only in electricity generation, but also in diagnosis and treatment in the health sector, defense industry, archaeological remains, and space studies. The energy density of uranium, the nuclear fuel, is very high compared to other traditional energy sources such as coal and oil (*Euronuclear,* 2024). Moreover, since they operate safely, their environmental damage is low. It also has low greenhouse gas emissions compared to fossil fuels, which have a high carbon footprint.

B. History

Established with the promise of cheap energy, nuclear power plants increased their popularity after the oil crisis in the 1970s with their promise of reducing dependence on external resources and ensuring supply security (IEA, 2023). Nuclear power is currently the second-largest form of low-emission energy globally, following hydropower and surpassing wind or solar PV. In developed countries, it is the primary source of low-emission electricity. Despite a period of slow growth after the Fukushima Daiichi Nuclear Power Station incident, changing policies are now opening up opportunities for a resurgence in nuclear power (IEA, 2022). At the end of 2023, 440 nuclear power reactors were operating in 32 countries around the world with a total capacity of 390 GW. These reactors meet 10% of the world's energy needs, avoiding 1.5 gigatonnes (Gt) of global emissions and 180 billion cubic meters (bcm) of global gas demand per year (Schneider & Froggatt, 2020). As of July 2024, 60 power reactors are in the process of construction in the world (WNA, 2024). Although the amount of electricity generated by nuclear power plants experienced a decline from 2010 to 2012, it has been in an upward trend after this period as is seen in Figure 2 (WNA, 2024). According to STEPS, nuclear power capacity is projected to increase from 417 GW in 2022 to 620

GW in 2050, with most growth occurring in China and other emerging market and developing economies. Meanwhile, advanced economies are focusing on extending the lifetime of existing facilities and considering new projects to offset retirements.

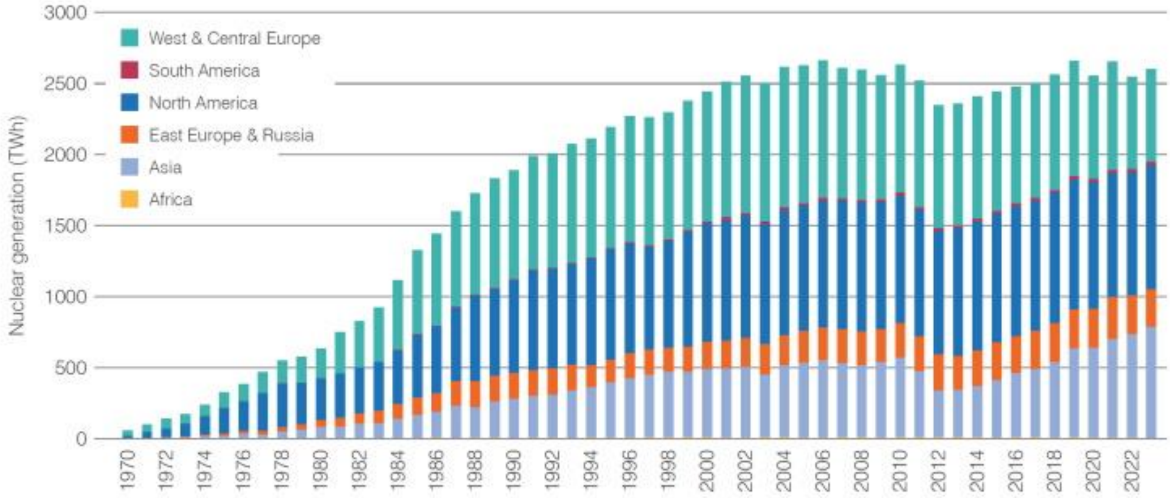

Figure 2. World's Nuclear Power Plant Energy Generation Trend (WNA, 2024).

The decision to install nuclear power plants is not usually made based on requests by the public, but rather by the decision of states. Generally, countries that make this decision are labor-intensive countries like Russia, China, and India. It is observed that developed countries that have completed their heavy industry phase and stabilized their economies tend to remain distant from nuclear power plants. The reason for this may be that the share of nuclear power plants in total electricity production reaches the saturation point, the low population growth rate, and the shrinkage in industrial growth rates (Temurçin & Aliağaoğlu, 2003).

Currently, countries can be divided into four groups based on their approach to nuclear power plants (Melikoglu, 2016):

- Countries in the Middle East, North Africa, and South America prioritize economic development.
- Countries such as Russia, Canada, India, and the United States have increased security measures.
- Countries like Japan, Spain, and Portugal currently have a stable approach and are slowing down their nuclear development.
- Countries like Germany and Sweden have announced that they will slow down and eventually end their nuclear efforts.

China can be considered an exception to this classification, with 150 nuclear reactors planned to be built by 2035 (Ezell, 2024). In 2022, thirteen nations generated a minimum of 25% of their electricity from nuclear power. Among them, France derives approximately 70% of its electricity from nuclear energy, while Ukraine, Slovakia, Belgium, and Hungary rely on nuclear power for about half of their electricity. Turkey is among the countries that prioritize economic development in the first group.

However, this picture started to change as of 2022. According to the European Union Agency for the Cooperation of Energy Regulators (ACER), retail electricity prices were on average 30% higher on an annual basis in February 2022 (ACER, 2022). Energy security concerns and the recent spike in energy prices, especially following Russia's invasion of Ukraine, have caused governments to rethink their energy security strategies and emphasized the value of a diverse mix of non-fossil and domestic energy sources. Currently, 60 reactors are under construction with a total capacity of 61 GW. Of these, 26.3 GW are being built in China, 5.4 GW in India, 4.4 GW in Turkey, 4.4 GW in Egypt, 3.8 GW in Russia, 3.3 GW in the UK, and 14 GW in the remaining countries combined (*IAEA*, 2024). In addition, the United Kingdom, France, China, Poland, and India have recently announced energy strategies that give nuclear power important roles. Belgium and Korea have recently withdrawn plans to phase out existing nuclear power plants

(Schneider & Froggatt, 2020). The status of nuclear power plants in the world as of 2023 can be seen in Table 1.

Table 1. The Status of Nuclear Power Plants in the World as of 2023 (Schneider & Froggatt, 2020).

Shut Down Reactors	5
Reactors Whose Construction Started This Year	7
Reactors Under Construction	60
Total Reactor Number	440
Total Installed Power	390 GWe

In addition to the construction of new reactors, life extension of existing reactors seems to be an important step for governments in recent times. Most of the existing reactors are now at the aging stage. Life extension of existing nuclear power plants seems to be one of the most important steps toward the net-zero target in 2050. Currently, reactors over 30 years old account for 63% of the total capacity. At this point, it is an important indicator that the US has given 20-year life extensions to its 88 reactors with 40-year operating licenses, France and Belgium offer 10-year life extensions, Hungary, Finland, Czechia, and the United Kingdom offer 20-year life extensions to reactors (Schneider & Froggatt, 2020). Similar to the 1973 oil crisis, the current energy crisis could lead to a similar resurgence of nuclear energy. The policy environment is changing, creating opportunities for the return of nuclear power.

In recent years, the costs of establishing a nuclear power plant have risen with increased safety measures and accidents. Additional costs due to safety, financial liabilities in crediting, and nuclear wastes are the main reasons for this increment.

The safety assessment of nuclear accidents and situations caused by nuclear energy is made according to the International Nuclear and Radiological Event Scale (INES). The first three levels are considered as "incident" and the last four are considered as "accident" on the scale, which includes levels from 1 to 7. While the nuclear accidents that took place in Chernobyl in 1986 and Fukushima in 2011 were classified as the 7th level, which is the highest level, the Three Mile Island accident that occurred in the USA in 1979 was rated as the 5th level. According to the INES scale, there have been 16 incidents that are level 4 and higher, which are considered accidents, between 1952 and 2020 (Wikipedia, 2020). There have been hundreds of events in the lower levels, four of which took place in 2020 (*IAEA*, 2024).

When an accident occurs in a nuclear power plant it is accepted that the material and moral damage will be much more than the benefit that the power plant has provided to society until then. Moreover, it is necessary to distinguish between the risk and the size of accidents in nuclear power plants (Gürbüz, 2011). Although there is a lower risk of a major accident occurring, the impact and damage will be national rather than local. Radioactive material released after such accidents has long-term effects such as leukemia, infertility, cancer, and hereditary diseases. In addition, since the 1950s, when nuclear power plants were first established, radioactive substances have been observed in the teeth and bones of children, and there has been an increase in breast cancer in women (Kaya, 2012).

One of the most important parameters used when comparing energy production facilities is the chemicals they release into the environment and their effects on the environment in general. As it is known, polluting gases such as sulfur dioxide (SO2), nitrogen oxide (NOx), and carbon monoxide (CO) are released during electricity generation from fossil fuels. These gases trigger global warming by causing the greenhouse effect (Kaya, 2012). Nuclear power plants produce minimal greenhouse gas emissions during operation. According to the International Atomic Energy Agency (IAEA), the lifecycle emissions of nuclear energy, including mining, fuel processing, and waste management, are comparable to those of wind and solar power (IAEA, 2020). Additionally, according to World Nuclear Association's (WNA) study, greenhouse gas emissions that occur in nuclear power plants is lower than renewable energy-based emissions (Kok & Benli, 2017).

The production of nuclear weapons is another issue to be considered when nuclear energy is in focus. These weapons are used three days apart for the first and last time in the human history. On August 6, 1945, the world's first deployed atomic bomb was dropped over the Japanese city of Hiroshima and three days later this time over the city of Nagasaki. In addition, more than 200 thousand people lost their lives in these cities, and the effects of cancer, hereditary diseases, and disabilities continue.

IV. **TURKEY'S NUCLEAR ENERGY OUTLOOK**

A. History

Turkey's history with nuclear energy dates back to 1956 when the country signed an information-sharing agreement with NATO in the nuclear field. That same year, the Atomic Energy Commission (AEK) was established to oversee studies on atomic energy. In 1957, Turkey joined the International Atomic Energy Agency (IAEA), a United Nations organization. And the first nuclear research center was built in Çekmece, Istanbul in 1962. Although a feasibility study for a nuclear power plant was launched in 1972 and the Akkuyu location was chosen, the project was not realized. Turkey made several attempts to launch tenders for nuclear power plants in 1976, 1983, 1993, and 1997. However, these attempts were cancelled following the 1979 Three Mile Island and 1986 Chernobyl accidents. After experiencing an energy shortage in 2000, Turkey reconsidered the idea of establishing a nuclear power plant.

When nuclear energy comes to the table for a country, it can be evaluated in three main sections. These are the reason why nuclear energy is demanded, namely the motivation, the financial, technological, and institutional infrastructure of the requesting country, namely the capacity, and which approach the requesting country adopts for this initiative, namely the strategy (Jewell & Ates, 2015).

A.A.1 Motivation

Many countries identify security of energy supply, meeting increasing electricity demand due to industrialization, reducing dependence on imported energy sources, combating global warming and preventing nuclear proliferation as the main motivating factors for investment in nuclear energy. In the case of Turkey, the main factors are security of supply, increasing electricity demand, reducing the current account deficit and employment. Turkey is heavily dependent on foreign energy sources as it has limited fossil energy resources other than lignite (Temurçin & Aliağaoğlu, 2003). Moreover, dependence on natural gas in energy production increases external dependence and poses a threat to security of supply. However, electricity generated from renewable energy sources cannot provide a stable generation performance due to its intermittent nature, making it a complementary energy source.

According to a study carried out by the Ministry of Energy and Natural Resources, the annual electricity demand was expected to increase by 6.3% in low demand prediction for the 2009-2018 period (TEIAS, 2009). However, this increase took place at 3.9% between these years, which means there was an increase in demand that was even below the low prediction. Ministry of Energy and Natural Resources does not have a study after this date, however, in another study (Bayrak, 2020) the annual average increase was predicted as 4.32%. If none of the licensed and pre-licensed projects are carried out, in 2025, it is estimated that the installed power reserve will be 35.9%, the project production reserve will be 20.3%, and the reliable generation reserve, which indicates the situation where all resources have the worst conditions, will be 2.8%. This demonstrates that if there is no addition to the current power plants, there will be no supply issues with the current capacity until the end of the year 2025. If that is the case, meeting the increasing demand is questionable. One also needs to take into consideration that the nuclear fuel for power plants cannot possibly be produced and processed in Turkey, which means that it is going to be imported. In addition, considering the amount of electricity to be paid in foreign currency for which a purchase guarantee is given, the issue of reducing foreign dependency and current account deficit should be reconsidered. It is clear that with the energy to be produced from this power plant, the need for imported natural gas and coal will decrease, but it should not be ignored that the compensation for this will not be done by the use of the country's resources, but by an energy production dependent on foreign resources. In the case of Akkuyu NPP, since this facility is the first nuclear power plant with the build-own-operate model in the world and the domestic industry contribution will be very low due to the nature of this investment model, it seems that the main priority of this project is to meet the country's energy needs (TÜBA, 2019).

When evaluated in terms of employment, in a VVER type power plant with 2000 MW power, it is expected for approximately 3500 staff to work in the power plant. It can be estimated that up to twice the number of staff will be employed in the power plant with a power of 4800 MWe to be established in Akkuyu (TASAM, 2012).

A.A.2 Capacity

The capacity section includes criteria such as the country's financial capability, appropriate legislation, academic infrastructure and qualified manpower. Turkey has a unique approach to capacity as it has agreed with the Russian government to build the Akkuyu nuclear power plant on a build-own-operate model, with the high investment cost covered by the Russian company. In addition, 300 Turkish students have so far studied in Russia at undergraduate level as part of the agreement (Defensehere, 2023). This arrangement allows Turkey to subcontract in areas it is currently unable to fulfill. While Turkey has previous experience with nuclear energy, it is unclear whether its academic infrastructure is ready and compliant with existing standards. While Turkish legislation is in line with international standards, it lacks detailed provisions on waste and spent fuel disposal, which in the case of the Akkuyu plant is the responsibility of the Russian company.

A.A.3 Strategy

The third section, Strategy, discusses the country's approach to nuclear energy. It covers topics such as using domestic resources, importing technology from foreign countries, and evaluating public opinion on nuclear energy. Turkey emphasizes the "national energy" title in their approach to nuclear energy, but in the case of the Akkuyu instance, the nuclear power plant will be owned by a Russian company and the fuel and main human resource will be provided by Russia. This is an unprecedented approach in the history of nuclear energy, as it's the first time a country has allowed another country to build a nuclear power plant on its soil (Jewell & Ates, 2015). This approach reflects Turkey's past failures in attempting to develop nuclear energy. According to World Bank data, Turkey has been one of the 35 most politically unstable countries in the world on average between 1996 and 2019 (Worldbank, 2019). In such an environment, and despite economic development, there has been a lack of demand for nuclear energy, which has propelled the country towards this approach. Furthermore, the state's decision on nuclear energy in Turkey holds more weight than the public's view of nuclear energy. To properly address this topic, it is important to first examine the social acceptance of nuclear energy. There are three main elements related to the acceptance of nuclear energy in societies: the safe operating condition of the facilities, the management of nuclear waste, and nuclear armament (Jewell & Ates, 2015).

In Turkey, there has been an "event" in which Cobalt 60 capsules were sold to junk dealers, which was evaluated as 3rd level on the INES scale (Ovalı, 2021). This event, which took place when there was no nuclear power plant in Turkey, as well as the fact that there is a high number of worker deaths and worker accident rates should be considered in terms of the culture of radiation safety. In addition, under Article 52 of the Radioactive Waste Management Regulation, the person authorized to operate the facility bears the responsibility for the storage and disposal of spent fuel and radioactive waste generated in nuclear facilities. In this context, the Russian company that is going to operate Akkuyu NPP is responsible for decommissioning the plant and managing the waste and fuel. Nuclear facility operators will store the low and intermediate-level waste within the facility and establish another facility for storing spent fuel. For the Sinop NPP project, under the agreement made with the Japanese government, the Republic of Turkey is responsible for managing radioactive waste and fuel. In addition, as stated before, Turkey, which made its stance on nuclear armament clear with the Treaty on the Non-Proliferation of Nuclear Weapons which it signed in 1980, has stated that it will not produce nuclear weapons and will only use this technology for peaceful purposes. As is known, nuclear power does not directly activate nuclear weapons programs. Also, having a nuclear energy program is not a requirement to have a weapons program. Yet, it should not be forgotten that having nuclear power can be an important factor in terms of military deterrence.

Because a country's nuclear energy experience (human resources, energy independence, etc.) can be considered a move that will strengthen its hand in international politics.

Despite initial skepticism, there has been a positive shift in Turkey's approach towards nuclear energy. However, this perspective began to change after a series of accidents. The Chernobyl disaster, which took place in close proximity to Turkey, had a radioactive impact on tea and hazelnut production in the Black Sea region (CNN Türk, 2018). This raised concerns about the safety of these crops and prompted questions about the overall safety culture. Even though the topic has been on the agenda many times, the public's opinion on this subject has not become clear. Although subjects such as energy supply security, reducing the current account deficit and employment are important factors in creating a positive public opinion; accident risk, nuclear waste, and communal experiences cause social uncertainty in this regard.

At this point, one can open a parenthesis to question which technology society will use and how. Because the technology society will use should be evaluated morally, not economically. If a technology promises serious economic prosperity to the country and society, yet if it poses a threat to the future of that society, then the economic parameters are insignificant. Especially if it is a technology that will affect not only the current period but also the future periods (as in the case of nuclear technology) then this selection should be examined very well. The Stockholm Declaration published in 1972 touches on this subject by stating "People have the fundamental right to favorable living conditions, equality and freedom in an environment of a quality conducive to a dignified and decent life" (Kaya, 2012). Arising from this responsibility, the necessity of an Environmental Impact Assessment (EIA) report for activities that may cause environmental problems has come to the agenda of the whole world and has become mandatory in Turkey in 1983. However, it should not be forgotten that reservations such as harm to human health and environmental impact put not only the countries investing in this energy but also all regions where nuclear facilities are located at risk.

For Turkey, it is necessary to compose a National Nuclear Energy Program and determine the related strategies. This is of critical importance in terms of inspection and regulation. In this regard, an in-depth safety philosophy should be a roadmap for a safe nuclear power plant installation. In-depth safety philosophy consists of legislation, inspection, and accident procedures in the design, and it includes systems from the fuel pallets in the innermost part of the reactor to the safety shells constructed as layers (TÜBA, 2019).

The developments in the safety field are usually shaped by experiences following nuclear accidents. During the Fukushima NPP accident, it was not completely clear which institution had the responsibility regarding nuclear safety. In this regard, by carefully examining this incompatibility in the pre-accident legislation of Japan, it should be clearly stated in the legislation which institutions to these authorities and responsibilities belong to. Turkey is adding the international safety principles determined after the Fukushima accident to its legislation. Moreover, the institution or organization responsible for the implementation of licensing and regulatory activities should be independent of the political authority. During the Fukushima NPP accident, the nuclear operations regulatory agency was subordinate to the country's energy supply authority. Similarly, the institution that will supervise the power plant in Turkey is the state institution, the Turkish Atomic Energy Authority. It is a contradiction that a government agency affiliated with the Ministry of Energy and Natural Resources undertakes the independent supervision of a project to be made with an interstate agreement.

B. Reserves of Turkey Nuclear Power Plants

Turkey's uranium reserves are about 12 thousand tonnes (Uranium and Thorium in the World and in Turkey, 2017). Therefore, fuel for nuclear plants, enriched uranium, and operating technology used in these nuclear power plants should be imported. In addition to uranium, studies are being carried out to use thorium as nuclear fuel. Turkey's thorium reserves are around 370 thousand tonnes, which corresponds to around 6% of the world's reserves (MTA, 2017). Besides the fuel alternatives uranium and thorium, boron mine can play a significant role in controlling the reaction rate within the reactor as it is good at neutron capture. Moreover, boron-doped materials can be used in the cooling function of the reactors (IAEA, 1996). Turkey has 73% of the world's boron reserves (Etimaden, 2019).

In the case of nuclear technology, uranium enrichment studies take an important place in the context of international politics. In a sense, Turkey's failure in nuclear power plants in its previous five initiatives cannot be fully understood without considering the political pressures of western states. However, in the last 15 years, the reactions against establishing nuclear power plants and the related embargoes have left their place for uranium enrichment studies (MUSIAD, 2021). In this conjuncture of events, where the same situation applies to not only Turkey but also Iran, criticism against nuclear facility establishment projects focuses on the topic of uranium enrichment studies. This can also be understood as a desire to remain dependent on these countries for fuel rods.

C. Akkuyu Nuclear Power Plant

Even though Turkey's ambitions in this area became more defined, it was unsuccessful in its first nuclear power plant tender in 1968-1969 due to economic and political problems. In the early 1970s, a feasibility study was carried out regarding the places where nuclear power plants could be established and Mersin-Akkuyu, Sinop-Inceburun, and Kırklareli-Igneada regions came to the fore. The second attempt in 1975-1976 failed due to the external embargoes following Cyprus Peace Operation in 1974. Turkey has put its stance on nuclear armament, which had developed in parallel with the nuclear energy discussions, with the Nuclear Non-Proliferation Treaty (NPT) it signed in 1980, stating that it will not produce nuclear weapons and will only use this technology for peaceful purposes. Although the steps accelerated with the establishment of the Turkish Atomic Energy Authority (TAEK) in 1982, the third attempt in 1982-1985 ended with uncertainties in legal regulation. After the Chernobyl disaster in 1986, Turkey suspended its nuclear power plant plans for a while, and lastly, Turkey's attempt in 1998-2000 was unsuccessful due to the violation of tender specifications and allegations of bribery (Özalp, 2017). Nuclear power plant installation attempts, which fluctuated throughout the following years, became an important item on the agenda once again with Turkey Electricity Trade and Contracting Inc.'s (TETAS) tender for the electricity purchase in connection with the power plant installation in Mersin-Akkuyu. But the tender in this attempt was canceled because of the absence of any bids other than Rosatom, the Russian State Nuclear Energy company. Following this event, in the sixth and last attempt; the "Agreement on Cooperation on the Establishment and Operation of a Nuclear Power Plant in the Akkuyu Field in the Republic of Turkey" was signed between the Republic of Turkey and the Government of the Russian Federation, thereby ending the long-running process with an intergovernmental agreement (Artantas, 2024). In 2013, a similar agreement was signed with Japan for the establishment of a nuclear power plant in Sinop.

The power plant being built in Akkuyu, consisting of 4 VVER-1200 type reactors with a total power of 4800 MWe, is similar to Russia's water-cooled type (PWR) Kalininskaya Nuclear Power Plant. It is based on the NPP-2006 serial project and is expected to meet about 10% of Turkey's electricity needs when fully operational by the end of 2028 (Report News Agency, 2023). Lightly enriched uranium dioxide will be used as fuel in the Akkuyu NPP, which will be operated by the Russian consortium, with an expected operational lifespan of 60 years (Akkuyu NPP, 2024). The average cost of power plant is estimated to be 20 billion dollars, and the first unit is expected to come to life in 2025, with the remaining units becoming operational sequentially until 2028 (WNA, 2024a). As of February 2025, the commissioning and testing phase of the onshore pumping station of the first unit of the power plant started and current status of the plant construction is as shown in Figure 3 (WNN, 2025).

Figure 3. Start-up work under way for pumping station of the first unit of the power plant (*WNN,* 2025).

Akkuyu NPP, Turkey's first large-scale nuclear power plant project, is predicted to make a significant contribution to meeting the country's electricity demand and reducing foreign dependency. The construction of the Akkuyu NPP is expected to reduce Turkey's dependence on natural gas imports, especially from Russia. It is also anticipated that the plant will contribute to the decrease of the current account deficit by reducing the country's energy import bill. However, concerns about safety, environmental impact, and economic viability remain. The BOO model, which involves foreign ownership and operation of the plant, has raised questions about long-term strategic control and the security implications of relying on a foreign entity for a critical national infrastructure project.

D. Sinop Nuclear Power Plant

In addition to the Akkuyu NPP, Turkey signed another intergovernmental agreement with Japan for the construction of the Sinop NPP in 2013 (*NEI*, 2013). This plant was initially planned to be built by a consortium led by Mitsubishi Heavy Industries and Itochu Corporation, with technical cooperation from France's Areva. The Sinop NPP, intended to have four ATMEA1 reactors with a combined power of 4800 MWe, faced significant challenges and ultimately did not progress under the original consortium. The first reactor was targeted to become operational by the late 2023, and all four reactors are expected to be operational by the 2030s (Akyüz, 2017). Unfortunately, the project, which was launched in 2013, was halted in 2019 due to cost increases.

Recently, Turkey's Nuclear Energy Company (TÜNAŞ) was granted "Owner" status in 2023 to lead the Sinop project, reflecting a new direction in Turkey's nuclear energy ambitions (NBP, 2023). But Turkey is still negotiating with Russia and South Korea as potential partners for the Sinop NPP (Power Technology, 2024). Environmental and legal processes are also ongoing within the scope of the project, in which Russia seems to be at the forefront. The cost estimate for the Sinop NPP has significantly increased, with recent reports indicating a potential investment of approximately $40 billion (*Daily Sabah*, 2023). This project aims to enhance Turkey's energy security, create jobs, and foster economic growth through the development of local industries related to nuclear power.

E. Cost of Electricity

For the sustainable development and growth of a country, energy must be supplied continuously, in the desired quality, with a reasonable price, clean, and safely (Özalp, 2017). One of these criteria is to examine whether the electricity to be generated from nuclear power plants has a reasonable price.

It is planned to produce 35 TWh of electricity per year from the Akkuyu NPP, which will be established under the agreement with Russia, and 34 TWh of electricity per year from the Sinop NPP (Kok & Benli, 2017). If these two power plants were currently operating, they would have met 21% of Turkey's 327

TWh (TEIAS, 2023) electricity demand in 2023. With the liberalization of the electricity market in Turkey, many privatizations have occurred in this sector, and the state has turned from being a service provider public institution to a structure that oversees the electricity market. In this context, Turkey has guaranteed that it will purchase 50% of the electricity to be produced from the power plant to be built in Akkuyu from the Russian company for 15 years for 12,35/kWh US dollar cents. The 2023 yearly average of the Market Clearing Price (PTF) in the Day-Ahead Market in the Turkish Electricity Market was 9.656 USD per kWh (EPİAŞ, 2025). Similarly, the guarantee of purchase was given to the Japanese consortium for 11.80 US dollar cents per kWh (Nogay, 2016). In addition, the cost of electricity is constantly increasing due to the ongoing exchange rate fluctuations in Turkey.

As the cost of establishing nuclear power plants is high, companies that build nuclear power plants look for a guarantee of purchase and some incentives in the countries where the plants are to be established. A similar situation holds for Renewable Energy Resources Support Mechanism (YEKDEM), where the Turkish state used an incentive mechanism for energy production from renewable sources and gave a 10-year purchase guarantee. In theory, it is reasonable for Turkey to give such a guarantee to Russia for Akkuyu NPP. However, in an assurance like this, the price per kWh must be competitive.

When nuclear energy is on the agenda, the preference for renewable energy sources over nuclear power plants is one of the most widely opposed arguments. When a nuclear power plant and a solar power plant with the same installed capacity are compared, nuclear power plants have 8 times more electricity generation potential (Karaveli et al., 2015). Moreover, nuclear power plants would be more advantageous compared to conventional thermal power plants in the case of a carbon tax in the future.

The economic viability of nuclear power is influenced by several factors including initial capital costs, operational and maintenance costs, fuel costs, and decommissioning costs. To evaluate the economic feasibility of nuclear power in Turkey, we can use the Levelized Cost of Electricity (LCOE), which represents the per-unit cost (typically in USD per MWh) of building and operating a generating plant over an assumed financial life and duty cycle.

The LCOE can be calculated using the Eq. 4 below:

$$\text{LCOE} = \frac{\sum_t (I_t + M_t + F_t)/(1+r)^t}{\sum_t (E_t)/(1+r)^t} \tag{4}$$

where:

- I_t is the investment expenditures in the year t,
- M_t is the operation and maintenance expenditures in the year t.
- F_t is the fuel expenditures in the year t,
- E_t is the electricity generation in the year t,
- r is the discount rate, and
- t is the year of the study.

By comparing the LCOE of nuclear energy with that of renewable sources such as wind and solar, as well as fossil fuels, Turkey can make informed decisions on its energy mix.

In the generation of fuel-based electricity, the ratio of the total cost of the fuel to the production cost is 80-85% for natural gas, 45-50% for coal, and 10-15% for nuclear. For example, if fuel prices are doubled, the cost of electricity increases by 66% in natural gas plants, 31% in coal plants, and only 9% in nuclear power plants. This clearly shows the importance of nuclear power plants in establishing a sustainable energy policy (Kok & Benli, 2017). Yet, the situation is slightly different in terms of the Levelized electricity cost. The Levelized Cost of Electricity produced from nuclear power plants has increased from $117/MWh in 2015 to $155/MWh in 2019 and the same cost is around $40/MWh and $41/MWh for solar and wind power (Bayrak, 2020). As it can be seen, while the cost of electricity produced from sources such as solar and wind decreases depending on the developments in production and installation, electricity cost in nuclear energy increases with the effect of safety-related costs. However, prolonging the operational life of existing nuclear power plants for unit electrical power generation appears to have the lowest Levelized Cost of Electricity of all energy sources compared to installing new power plants (IEA & NEA, 2020).

Using the high amount of heat that is released while generating electricity from nuclear power plants will also increase the general efficiency of these systems. One can benefit from the waste heat obtained from these power plants in hydrogen production, water treatment, process heat as well as district heating.

F. SWOT Analysis

SWOT analysis is a strategic planning technique that provides assessment tools by identifying the internal and external factors affecting a business or investment. It helps to make more careful and informed decisions by assessing internal factors such as strengths or weaknesses and external factors such as opportunities and threats. This section presents a SWOT analysis of some of the factors considered in this study. Turkey's approach to nuclear energy is shown in Table 2 with strengths, weaknesses, opportunities and threats.

Table 2. SWOT Analysis of Nuclear Energy in Turkey.

Strengths	**Weaknesses**
• High capacity factor • High process heat • Low carbon emissions • Reliable base-load electricity • High boron and thorium reserves • The government's strong commitment to the nuclear power sector • Strategic location to serve as a transit hub for energy exports	• Low uranium reserves • The presence of another country's power plant on its territory • High security costs • Imported uranium supply • Low public acceptance • Limited experience and infrastructure in nuclear energy • Dependence on foreign technology and expertise
Opportunities	**Threats**
• Commercialization of new types of thorium-fueled reactors • Use of boron doped materials in reactor cooling • Reliable source for achieving sustainability goals • An option to fight climate change • Small modular reactors • Ability to diversify the energy mix and reduce dependence on imported energy sources	• High rates of occupational accidents and worker fatalities in Turkey • Continued dependence on foreign fuel • Terror threat • Political risks under intergovernmental agreements • Public opposition to nuclear power and accident potential

F.A.1 Strengths

The high capacity factor and reliable base-load electricity of nuclear power plants provide a steady and dependable source of energy. Additionally, the low carbon emissions of nuclear energy align with the global push towards reducing greenhouse gas emissions and combatting climate change. The country's abundant reserves of boron and thorium, as possible nuclear fuels, are another strength. The government's strong commitment to developing the nuclear energy sector further strengthens Turkey's position in this field. The strategic location of the country also provides opportunities for it to serve as a transit hub for energy exports, further expanding its reach in the energy sector.

F.A.2 Weaknesses

A poor reserve of uranium can limit the country's ability to produce nuclear energy domestically. Furthermore, having another country's power plant located on its territory may pose regulatory and safety concerns, as well as limit the country's control over its energy production. High safety costs associated with nuclear energy, as well as the reliance on imported uranium supplies, can also impact the financial viability of the energy sector. Additionally, low public acceptance of nuclear energy can create challenges in gaining support for new projects and ensuring the long-term success of the sector. Finally, the limited experience and infrastructure in nuclear energy, as well as the dependence on foreign technology and expertise, can limit the country's ability to develop and maintain a robust nuclear energy sector.

F.A.3 Opportunities

The commercialization of new types of Thorium-fueled reactors and the use of boron-doped materials in reactor cooling can increase the efficiency and safety of the country's nuclear energy infrastructure. Additionally, in the event of a future carbon tax, nuclear power plants may become more financially advantageous compared to thermal power plants. Nuclear energy can also play a role in the fight against climate change by providing a low-carbon source of energy. The development of small modular reactors can increase the flexibility and scalability of the energy sector, while reducing the costs associated with building and maintaining large power plants. Finally, the ability to diversify the energy mix and reduce reliance on imported energy sources can increase the country's energy independence and security.

F.A.4 Threats

High occupational accident rates and worker fatalities in the country raise concerns about the safety of the workforce in the energy sector. Additionally, the continued dependence on foreign fuel can increase the country's vulnerability to supply disruptions and price fluctuations. The terror threat and political risks associated with intergovernmental agreements pose additional challenges to the stability and security of the energy sector. Finally, public opposition to nuclear energy, as well as the potential for accidents, can limit support for new projects and damage the reputation of the nuclear energy.

V. Conclusion and Policy Implications

Turkey is a foreign-dependent country that meets most of its electricity production with fossil fuels. This situation carries risks in terms of supply security. To eliminate these risks, as stated in Turkey's goals, the country desires to invest in renewable energy sources while realizing the establishment of a nuclear power plant it aimed for more than half a century. However, Turkey's path in this regard contradicts one of its main motivations, reducing dependency on external resources, as the fuel to be used in these power plants will be produced and processed abroad and then imported. In addition, the guarantee of purchase given in foreign currency does not seem to be a factor that can reduce the current account deficit. Akkuyu NPP is going to be constructed with the build-own-operate investment model, the first of its kind in the sector, and will be the first nuclear power plant to be owned by a country that is within the borders of another country.

Turkey is a country that does not have a good report in terms of safety culture. A high number of worker deaths and a high rate of work accidents should be taken into account for the culture of radiation safety. In this context, which institutions have the authority and responsibility should be clearly stated in the legislation. In addition, the authority and responsibilities of the institution that will execute licensing and regulatory activities should be clearly defined and should have a supervisory and regulatory mechanism independent of the state structure. Similarly, it should be clearly stated by whom and how the nuclear wastes generated in the power plants will be disposed of.

It is expected for nuclear energy to have a significant function in a sustainable energy policy. Studies on using thorium as the nuclear fuel and the use of boron reserves in controlling reaction rate and as a coolant in the power plants would be an important step for Turkey, which is advantageous in the reserves of these two mines. Moreover, with the commercialization of new thorium-fueled reactors, foreign dependence on fuels can be prevented.

The previous approach of western countries to the establishment of nuclear power plants, which is one of the most important reasons behind Turkey's unsuccessful attempts has now left its place to uranium enrichment studies and fuel rods. It should be kept in mind that this perception change in the international public opinion reflects positively on Turkey's nuclear power plant projects, but if the next step is taken with further nuclear development studies, there may be reactions, embargoes, and international sanctions once again. For this reason, providing domestic equipment and technology support in such situations is of great importance in terms of reducing foreign dependency.

Overall, Turkey's approach to nuclear energy faces a mix of challenges and opportunities. While the high capacity factor, low carbon emissions, and strong government commitment offer advantages, the limited experience and infrastructure, dependence on foreign technology and fuel, and public opposition pose significant threats. However, the commercialization of new reactors, flexibility of small modular reactors, and potential for reduced carbon emissions and energy independence are opportunities for the country to further develop its nuclear energy sector.

Turkey, as in the examples of South Korea and Japan, desires to construct the third nuclear power plant with its resources after taking these steps. Therefore, Turkey sees these first steps as a transition period. Yet, Japan was only able to build its sixth nuclear power plant with its resources, while South Korea built its ninth nuclear power plant with its resources (Jewell & Ates, 2015). Considering these situations, the time elapsed between the first nuclear power plant and the first domestic nuclear power plant seems to be longer than Turkey envisages.

Despite such negative indicators, Turkey's desire to accelerate its steps in the field of nuclear energy may stem from its desire as a developing country to diversify its resources and meet its increasing energy needs from a reliable source. And it seems that the future of nuclear energy in the world will be based on agreements between governments and Turkey's initiative will provide a significant reference for other initiatives in the future.

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