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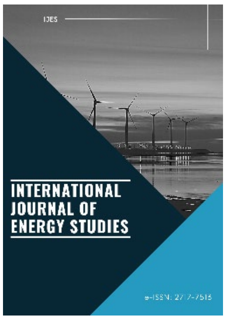

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Evaluating the build-own-operate model for nuclear power plant projects; A case study of Türkiye's first nuclear power plant agreement with Russia

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Highlights

- The Build-Own-Operate contracting model presents a novel approach to NPP projects.
- The Build-Own-Operate model has several advantages and disadvantages over traditional contracting models for nuclear power plants.
- The Akkuyu NPP project in Türkiye represents the world's first nuclear power plant project implemented under the Build-Own-Operate model.
- Lessons learned from Türkiye's experience with the Build-Own-Operate model can influence future nuclear energy projects around the world.

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ABSTRACT

This paper evaluates the Build-Own-Operate (BOO) model for nuclear power plant projects, using Türkiye's first nuclear power plant agreement with Russia as a case study. Nuclear energy is crucial for addressing global energy demands due to its reliable baseload power and zero greenhouse gas emissions. However, the industry faces significant challenges, including high costs and long commissioning times, which are influenced by contracting types. Traditional models like turnkey, split package, and multi-contracts present several limitations in terms of payment structure, cost, technology, and knowledge transfer.

The BOO model offers an alternative, where the contractor is responsible for the design, commissioning, ownership, and operation of the plant throughout its operational life. This approach can lead to timely project completion, deferred payment obligations, and reduced operational risk but requires careful consideration of potential drawbacks such as knowledge transfer, cost control, and long-term operational dependence.

The Akkuyu Nuclear Power Plant in Türkiye, developed under an agreement with Russia, is the world's first nuclear power plant implemented through this new model. This project highlights the innovative nature of the BOO model, detailing the benefits and challenges faced, including technology and knowledge transfer, cost structures, and localization efforts. The study provides a comprehensive analysis of the BOO model's potential in the nuclear industry and offers valuable lessons for future nuclear power projects globally.

Keywords: BOO model, Contracting models, Nuclear energy, Akkuyu NPP

1. INTRODUCTION

Nuclear energy presents a promising solution for growing global energy demands, offering a reliable baseload power source with zero greenhouse gas emissions. This makes nuclear energy a key player in energy transition and popular among both developed and developing countries [1]. On the other hand, the global nuclear energy industry faces significant challenges, including the need to reduce costs, shorten commissioning time, improve safety, and address environmental concerns. One approach to addressing last two challenges is the development of advanced nuclear power plants [2]. The high costs and long commissioning time are related to contracting types. Another approach to addressing first two challenges is the use of alternative contracting models for nuclear power plant (NPP) projects.

Traditional contracting models, such as turnkey, split, and multi-contracts, have been widely used in the industry [3], but they have limitations in terms of payment structure, cost, technology, and knowledge transfer [4]. In addition to these factors, there is a desire for alternative models to address deficiencies in technical capacity, skilled personnel, project management expertise, financial resource allocation, strategic partnerships, and risk mitigation [19].

The Build-Own-Operate (BOO) model presents a novel approach to NPP projects, which involves the contractor taking full responsibility for the design, commissioning, ownership, and operation of the plant throughout full operating life [5]. This model has been used in other industries, such as power generation and water treatment, but it is relatively new in the nuclear energy sector [6]. The BOO model offers potential benefits for timely project completion, deferred payment obligations, and reduced operational risk [7]. According to Jong Kyun Park, IAEA division of Nuclear Power, “This method solves two of biggest problem that newcomer countries face; experience operator and financing” [18]. However, careful consideration is needed to address potential drawbacks related to knowledge transfer, cost control, and long-term operational dependence.

The use of the BOO model in nuclear energy projects has been limited, but there is one notable example; the Akkuyu Nuclear Power Plant in Türkiye, which is being commissioned through an agreement with Russia using the BOO model [7]. Türkiye, with its rising energy demands and diversification goals, has embarked on a nuclear energy program. A critical aspect of this program involves the construction of its first NPP. This project offers a unique opportunity to investigate the impacts of the BOO model on NPP projects.

In this paper, the various contracting models for NPP projects and the advantages and disadvantages of the BOO approach in the context of the Türkiye-Russia agreement are investigated. By examining specific provisions related to technology and knowledge transfer, cost structures, and localization efforts, this study aims to contribute to the understanding of the BOO model's potential benefits and challenges in the nuclear industry. The primary objectives of this paper are to analyse the lessons derived from the inaugural BOO nuclear contract and to propose potential solutions for the challenges encountered during the Akkuyu nuclear power plant project. By doing so, this paper aims to assist newcomer countries in assessing the viability of the BOO model for their own nuclear power plant projects.

2. TRADITIONAL CONTRACTING MODELS FOR NUCLEAR POWER PLANTS

In the nuclear power industry, there are various contract models such as turnkey, split package, and multi-contracts. The choice of contracting model depends on a range of factors, including the overall licensing approach of a country, financial structure, and the experience in the sector.

The turnkey approach is a traditional model used in the energy industry, in which a single contractor or a consortium of contractors takes overall technical responsibility for the construction work. This approach gives the contractor much more influence over project management. However, it also shifts all major risks to the contractor, including cost and design [8]. Therefore, it is essential to have a realistic work schedule, a completed design before works start on site, a detailed knowledge of the regulatory requirements [9]. This approach offers low risk to client, however limits technology and knowledge transfer for the client.

In split package contracting, the technical responsibility is divided among a limited number of contractors, each constructing a significant section of the plant. This approach can lead to delays due to connection of each work package if there is a failure in coordination between the separate packages of work. Therefore, it is essential to limit the number of subcontractors and reduce interfaces where possible. For some key items such as turbine-generator set, and waste management, a single contract package could be placed, to ensure single-point responsibility for each of these key items [10]. This approach presents higher risk to clients, however, potentially enhance technology and knowledge transfer [11].

In multi-contracting, the client is responsible for coordinating the separate packages of work and ensuring effective communication and interfacing between them. This model offers greater control over costs and potentially enhance knowledge and technology transfer, on the other hand, it requires a more complex project management structure for the client and can lead to significant delays, and performance issues if there is a failure in coordination. A study by Y.Y.Ling, 2002 explored the challenges and benefits of multi-contract contracting in large-scale power plant project in East Asia, highlighting the importance of robust project management and risk mitigation strategies. Their findings provide lessons to be learned for application to future large-scale and complex projects such as "work could not progress smoothly, inaccuracy of project information, ineffective communication and excessive change orders" [12].

In summary, each contracting model has its advantages and disadvantages. A comprehensive evaluation of project-specific factors is essential to select the most suitable model for a nuclear power plant project. Table 1 shows examples of each contract type and project details.

Table 1. Contract type and project details

Contract Type	Project	Client	Contractor	Reactor Type
Turnkey	El Dabaa	Egypt	ROSATOM	VVER
Split Package	Flamanville-3	EDF	Framatome, Equans	EPR
Multi-contracting	Olkiluoto	TVO	Areva, Siemens	EPR

3. THE BUILD-OWN-OPERATE MODEL

The BOO model is a relatively new approach in the nuclear power industry, where the donor company or country builds, pays for and owns the nuclear power plant, while the host country provides the site and necessary infrastructure [13].

The BOO model has several advantages over traditional contracting models for nuclear power plants. Firstly, it allows knowledge and technology transfer from the donor company to the host country, which can help build the host country's capacity in nuclear energy. Secondly, it limits the financial responsibilities on the host country during the commissioning period, as the donor country assumes the upfront costs of commissioning. Thirdly, it can result in faster project completion times, as the donor country has the expertise and resources to efficiently manage the commissioning process.

On the other hand, the BOO model also has some potential challenges. One concern is the long-term operational dependence on the donor company, as the host country may not have the necessary expertise to operate and maintain the plant independently [14]. Additionally, there may be issues around localization of manufacturing capabilities, as the host country may have limited influence over the local manufacturing of NPP components. Finally, concerns may arise around knowledge and technology transfer, as the host country may not have the opportunity to fully participate in the design and construction process [14]. To address these potential challenges, it is important for host country to carefully consider the specific obligations of the BOO agreement, particularly around technology and knowledge transfer, localization of manufacturing capabilities, and cost structure of power purchase agreement.

Figure 1: The location of Akkuyu NPP

In summary, the BOO model is a promising approach for nuclear power plant projects, offering potential benefits in term of knowledge and technology transfer, experience transfer in project management, and faster project completion times. However, careful consideration of the specific obligations of the BOO agreement is needed to ensure that the host country can fully benefit and increase the experience from the project.

4. CASE STUDY: TÜRKİYE'S FIRST NUCLEAR POWER PLANT AGREEMENT

The Akkuyu NPP, designed based on the VVER-1200 model, has a total capacity of 4,800 MW, comprising four units of 1,200 MW each, making it a vital energy infrastructure project for Türkiye [16]. This project not only represents a significant step to towards meeting Türkiye's intentions to use nuclear technologies but also serves as a strategic move to enhance energy supply security and reduce reliance on foreign fuel sources. Additionally, this project will assist Türkiye in meeting its goals to decrease carbon emissions, as promised by signing the Paris agreement in 2016 [17].

The Akkuyu NPP project in Türkiye represents the world's first nuclear power plant project implemented under the BOO model. The contractor of project is ROSATOM, the Russian state nuclear corporation. This project demonstrates the innovative nature of the BOO model in the engineering, commissioning, operation, maintenance, and ownership of the plant [14]. Under the Intergovernmental Agreement (IGA) signed between Russia and Türkiye in 2010, Akkuyu Nuclear Joint Stock Company (JSC) was established on the 13th of December 2010 and JSC maintains sole ownership of both the Akkuyu NPP and the electricity it generates. Initially, 100% of the Project Company's equity was held by Russian investors, with Concern Rosenergoatom JSC controlling a substantial portion (92.85%).

The IGA mandates that Russian investors maintain a controlling interest in the Project Company, with their cumulative share never falling below 51%. To participate, Russian investors must obtain government authorization from the Russian Federation. The IGA also stipulates according to Article 5 that the Russian party should actively seek foreign investment, primarily from Turkish sources. However, the allocation of the remaining 49% of the Project Company's shares remains contingent upon the approval of the Republic of Turkey, ensuring that the project aligns with national interests, security, and economic objectives [20]. This dual approval process underscores the project's sensitivity to political dynamics and the bilateral relationship between Russia and Türkiye.

Akkuyu JSC took on the responsibility for the entire project lifecycle, from design to operation and from waste management to decommissioning, marking a significant milestone in nuclear energy cooperation between the two countries. Table 2 shows the technical specifications of Akkuyu NPP project.

According to IGA, Power Purchase Agreement (PPA) was signed for 15 years. It obligates Türkiye to purchase 70% generated electricity of Unit 1 and 2 and 30% of Unit 3 and 4 at average price of 12.35 cents/kwh. The price includes investment cost, operating cost, fuel cost, transportation of fuel and spent fuel, waste management and decommissioning of the NPP. Akkuyu JSC must make a separate payment of 0.15 cent/kWh to spent fuel account and another 0.15 cent/kWh payment to decommissioning account for the electricity purchased by Turkish side. 20% of net profits of Akkuyu JSC will be transferred to Turkish government [20].

The surplus electricity (30% electricity of Unit 1 and 2, 70% of Unit 3 and 4) and the electricity generated from Akkuyu NPP after PPA ends, can be marketed to both domestic Turkish markets and government at variable prices (Article 10). Additionally, the strategic location of Akkuyu NPP, as illustrated in Fig. 1, offers significant advantages to Akkuyu Nuclear JSC, given its proximity to Syria and Cyprus. In the aftermath of the Syrian civil war, the Syrian government is anticipated to initiate extensive urban reconstruction and industrial redevelopment, thereby increasing the demand for electricity—a demand that Akkuyu Nuclear JSC is well-positioned to meet. Furthermore, the northern part of Cyprus, subject to international sanctions due to political issues, presents a potential market for electricity from Akkuyu NPP. An agreement to supply electricity to Cyprus could constitute a mutually beneficial trade arrangement. Consequently, Akkuyu JSC has multiple market opportunities for the sale of surplus electricity.

Currently, there are no publicized plans within the Akkuyu project to utilize the excess electricity for energy-intensive applications such as water desalination or hydrogen production. The primary goal of the Akkuyu NPP project remains the generation of electricity for Türkiye's national grid. However, future considerations may include the application of electricity during periods of low demand for such purposes. At present, Akkuyu JSC retains several options for marketing electricity to both domestic and international markets.

According to Article 3/2.24 and 2.25 of IGA includes obligations for knowledge and technology transfer in the field of licensing, safety and security in radiation and nuclear activities, supervision of nuclear facilities and localization of manufacturing capabilities, with the aim of building

Türkiye's capacity in nuclear energy. The knowledge and technology transfer will be facilitated on a non-financial basis for the Turkish party [20].

Lessons Learned from Akkuyu Project and BOO Contracting Model

Lessons learned from the Akkuyu project highlight the challenges and opportunities associated with implementing a nuclear power program in a newcomer country like Türkiye. It has been 14 years since the signing of IGA and it has been more than 6 years since taking construction permit of Unit 1[21] therefore initial outcomes can be analysed.

Despite numerous efforts by the Turkish government to participate in the global nuclear energy landscape through various contractual models since 1950, all previous attempts have been unsuccessful. As of October 2024, Unit 1 of the Akkuyu NPP, constructed under the BOO model, is nearing completion and is expected to become operational in 2025, according to the Minister of Energy and Natural Resources [22]. The successful implementation of the BOO contracting model for Akkuyu Nuclear Power Plant suggests that it is a viable option for countries with limited financial resources seeking to enter the nuclear energy sector.

After signing of the IGA, more than 150 students have been educated in various Russian universities in different fields and have begun working at the Akkuyu NPP. These students have been facilitating the experience and knowledge transfer from Russia to Türkiye. Turkish Energy, Nuclear and Mineral Research Agency (TENMAK) and Nuclear Regulatory Authority (NDK) have cultivated expertise in the licensing, safety, and security of nuclear power plants. It is reasonable to infer that Article 3, Clauses 2.24, 2.25, and 3 of IGA have been effectively implemented.

Moreover, approximately 10,000 job has been created during the construction period which have a great impact on local public acceptance of nuclear energy. Furthermore, after completion of 4 units, the Akkuyu NPP is expected to produce 10% of electricity of Türkiye's demand, significantly contributing to long term national energy supply security. Another expected advantage is the localization of manufacturing in the commissioning of the Akkuyu NPP, with an estimated 40% of manufacturing capabilities being localized. As more local companies have been involved in manufacturing, localization of manufacturing capabilities and technology transfer have been expected to increase.

Table 2. Technical specifications of the Akkuyu NPP

Contract Type	BOO
Project	Akkuyu NPP
Reactor Type	VVER 1200
Capacity	4 units, 4 X 1200 MW
Contractor	ROSATOM
Contractor Responsibilities	Financing, Design, Commissioning, Operation, Maintenance, Spent fuel treatment, Decommissioning
Client	Türkiye
Client Responsibilities	Site allocation, grid connection, site infrastructure
Total Cost	Appox. $25 bln
Lifespan of NPP	60 years with an extension 10 year

However, there have been concerns about cost structure and operational dependence, with some critics arguing that the agreement is too heavily weighted in Russia's favor. When analysing the PPA, the price of electricity is 12.35 cents/kwh, Hinkley Point C electricity costs 11 cents/kwh, suggesting that electricity from the Akkuyu NPP is slightly expensive. This discrepancy can be attributed to the long-term back payments and extensive responsibilities borne by the Russian party. In essence, these additional costs represent the price associated with the advantages offered by BOO contracting model.

Furthermore, The BOO contracting model, while innovative, is uncharted territory in the realm of nuclear energy projects. This novelty introduces inherent risks due to the unpredictable nature of such endeavours. As a pioneer in this field, the Akkuyu Nuclear Power Plant project lacks the benefit of learning from prior experiences or knowledge transfer from similar initiatives.

Moreover, The BOO contracting model often involves a geographical separation between the NPP owner and the client nation. Despite the owner's responsibility for spent fuel, waste management, and decommissioning, the cross-border nature of these operations can pose significant challenges due to radioactive waste and spent fuel transportation restrictions. Therefore, these issues must be explicitly addressed in the contractual agreements. The IGA between Türkiye and Russia serves as a cautionary example, as it contains unclear provisions related to the storage and disposal of spent nuclear fuel. For instance, Article 12, Clause 2, informs that Russian-origin spent fuel may be reprocessed in Russia, subject to a separate agreement. However, the specific location and method of storage remain unclear. Furthermore, Russian regulations prohibit the transfer of nuclear waste from other countries to Russia, compounding the uncertainty regarding waste management. It is imperative that future BOO contracts for nuclear power projects clearly delineate responsibilities and procedures related to spent fuel and waste management.

Furthermore, BOO contracting models for nuclear power projects must explicitly outline penalties and responsibilities associated with project delays. Contractors often face deadlines for completing construction and achieving operational status. To mitigate the financial impact of delays on the client, contractual provisions typically include penalties that encourage timely project completion. However, the Akkuyu NPP project presents a notable indefiniteness in this regard. Despite a seven-year construction timeline from the date of issuance of construction permit stipulated in Article 6, Clause 2 of the project agreement, the current trajectory suggests a potential delay in taking Unit 1 into operation. While Article 10, Clause 11 outlines adjustments to the electricity price in case of delays, the specific terms and conditions for these adjustments remain unclear within the PPA. To ensure project accountability and mitigate risks, future BOO contracts should clearly define responsibilities, penalties, and procedures related to project delays. Further outputs of BOO contracting model and Nuclear NPP agreement can be evaluated after the Akkuyu NPP begins commercial operation and grid connection.

5. CONCLUSION

The implementation of the BOO model in Türkiye's first nuclear power plant project with Russia marks a significant milestone in the country's energy landscape. The BOO model offers advantages such as potential knowledge and technology transfer, localization of manufacturing capabilities and experience transfer in project management, but it also presents challenges related to cost control, and long-term operational dependence. The case study of the Akkuyu NPP underscores the importance of carefully evaluating the specific obligations of the BOO agreement to ensure alignment with Türkiye's strategic energy goals and regulatory framework.

The Akkuyu NPP project, has provided valuable insights since the signing of the IGA. Key lessons learned include:

- ***The viability of the BOO model:*** The successful implementation of the BOO model for Akkuyu demonstrates its potential for countries with limited financial resources seeking to enter the nuclear energy sector.
- ***Knowledge and technology transfer:*** The BOO model has facilitated the transfer of technology and knowledge, enabling participating nuclear regulatory authorities to gain expertise in licensing, safety, and security of nuclear facilities.
- ***Importance of clear contractual terms***: Future BOO contracts should explicitly outline responsibilities and procedures related to spent fuel management, waste disposal, and decommissioning.
- ***To ensure project accountability and mitigate risks:*** future BOO contracts should clearly define responsibilities and penalties, related to project delays.
- ***The need for project oversight:*** The Akkuyu project highlights the importance of effective oversight and monitoring mechanisms to address potential challenges and ensure project timelines are met.

The successful application of the BOO model in Türkiye's nuclear energy sector serves as a valuable example for other countries considering similar nuclear power projects. By leveraging international partnerships and innovative contract models, Türkiye demonstrates its commitment to further developing nuclear energy expertise, improving energy supply security. Lessons learned from Türkiye's experience with the BOO model can influence future nuclear energy projects around the world and guide policymakers address the complexities of knowledge and technology transfer, cost structures and localization of manufacturing capability in the nuclear sector.

The Akkuyu NPP has yet to commence commercial operations, limiting the availability of empirical data regarding project delays, spent fuel management, and nuclear waste management. Consequently, these aspects represent the primary limitations of this study. Future research should focus on the project's completion timeline, operational experiences, and the effective management of spent fuel once the NPP becomes fully operational.

NOMENCLATURE

BOO	Build Own Operate
EDF	Electricité de France
EPR	European Pressurized Reactor
IGA	Intergovernmental Agreement
JSC	Joint Stock Company
NPP	Nuclear Power Plant
NDK	Nuclear Regulatory Authority
PPA	Power Purchase Agreement
TENMAK	Turkish Energy, Nuclear and Mineral Research Agency
TVO	Teollisuuden Voima Oyj
VVER	Water-Water Energetic Reactor

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DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Mahmut Cüneyt Kahraman: Analysed the case, wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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