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Original Article

Challenges in nuclear energy adoption: Why nuclear energy newcomer countries put nuclear power programs on hold?

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ABSTRACT

The pressing need to mitigate greenhouse gas emissions has stimulated a renewed interest in nuclear energy worldwide. However, while numerous countries have shown interest in nuclear power over the course of history, many of them have not continued their pursuit and chosen to defer or abandon their peaceful nuclear power projects. Scrapping a national nuclear power program after making initial efforts implies significant challenges in such a course or a waste of national resources. Therefore, this study aims to identify the crucial factors that influence a country's decision to terminate or hold off its peaceful nuclear power programs. Our empirical analyses demonstrate that major nuclear accidents and leadership changes are significant factors that lead countries to terminate or defer their nuclear power programs. Additionally, we highlight that domestic politics (democracy), lack of military alliance with major nuclear suppliers, low electricity demand, and national energy security environments (energy import, crude oil price) can hamper a country's possibility of regaining interest in a nuclear power program after it has been scrapped, suspended, or deferred. The findings of this study have significant implications for policymakers and stakeholders in the energy sector as they strive to balance the competing demands of energy security, and environmental sustainability.

1. Introduction

Nuclear energy has long been regarded as one of the best solutions for meeting the world's energy demands because of its stable base load operation capability with low carbon emissions [1]. This low-carbon emission advantage of nuclear energy production has led to over 30 countries building and operating commercial nuclear power plants (NPPs), and many others are expressing interest in nuclear energy [2]. The energy crises faced due to the Russian invasion of Ukraine and the related energy price hike have also made alternative energy sources, including nuclear energy, more appealing in terms of energy security than relying on Russian natural gas. In response to this, major nuclear energy export countries are driving the export and development of not only large commercial reactors, but also small reactors that can be manufactured in factories through modularization for countries new to nuclear energy [3]. Given these observations and the growing interest in achieving carbon neutrality in both exporter and client countries, it is expected that the use of nuclear energy will continue to gain momentum.

As such, it has been crucial to analyze what are the driving motivations and surrounding environment that could lead the countries to deploy NPPs successfully. Scholars have continuously examined the main driving factors that help countries to deploy commercial NPPs in their countries [4–6]. Previous literature has used economic development, energy security, nuclear accidents, domestic politics, supply dynamics, and the international market (i.e., the proximity of a country to a major technology supplier) to examine whether these factors have played significant roles in NPP deployment. Although there are discrepancies in the factors claimed to be significant by each study, most studies emphasize that complex mechanisms such as politics, economy, and military have affected in nuclear power technology adoption.

In spite of the emerging interest in the expansion of nuclear energy, history tells that many countries have halted the construction of NPPs or scrapped the nuclear power development plan despite their national motivations. In other words, the expressed interest in NPP construction

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Abbreviations

CHISOLS	Change in Source of Leader Support
GDP	Gross Domestic Product
IAEA	International Atomic Energy Agency
NEN	Nuclear Energy Newcomer
NPP	Nuclear Power Plant
TMI	Three Mile Island

did not materialize for various reasons in those countries. In 2009, more than 50 countries announced that they were pursuing nuclear power programs [7], but ultimately only a few have succeeded to date. For example, Thailand, Indonesia, and Vietnam have deferred their plans although these countries have interests in building NPPs. Other countries, such as Cuba and North Korea have halted the construction of NPPs in the interim. Given the very extensive nature of preparation for NPP construction, scrapping such a project implies a loss in large national expenditure.

It is widely known that nuclear energy newcomer (NEN) countries have encountered barriers in terms of finance, technology, etc., to install even a single NPP [7]. However, few studies have comprehensively and quantitatively evaluated the NEN countries' decision to scrap, suspend, or defer their nuclear energy programs. In that sense, elucidating the reasons that hinder a country's adoption of nuclear power technology, and prevent them from regaining their interest, can help NEN countries strategically succeed in adopting it or not to waste national resources in the foreseeable future.

It is therefore meaningful to examine the factors explaining why the rising number of NEN countries suspended peaceful nuclear power deployment plans in the past. To address this issue, this paper seeks to understand the causes and provide insights into how future nuclear power development projects can be made more successful in NEN countries. In a nutshell, answers to the following questions are analyzed in this paper.

1) Why do NEN countries maintain scrapping, suspension, or deferral positions of their nuclear power deployment plans after making initial efforts?
2) Why do NEN countries decide to scrap, suspend, or defer their nuclear power deployment plans after making initial efforts?

To go beyond the previous literature, this study takes a different approach from the existing studies by constructing a timeline dataset of countries that have scrapped, suspended, or deferred to deploy nuclear power technology. This study uses variables that are found to be important in explaining the adoption of nuclear energy, to examine whether these factors conversely affect the NEN countries to scrap their nuclear energy programs. The study also employs country fixed effects to account for individual country characteristics that may affect the decision. In total, 51 countries are analyzed in this study.

By incorporating a series of empirical analyses and robustness checks, we find that electricity demand, energy security environment, and major nuclear accidents play significant roles in a country's decision to maintain scrapping, suspension, or deferral positions of their nuclear power programs. Our analysis further indicates that a country's democratic status and lack of military alliance with major nuclear supplier countries may also play an important role in their decision to maintain scrapping, suspension, or deferral positions of nuclear power programs. Lastly, we further show that the decision of scrapping, suspension, or deferral of nuclear power program is mostly derived when the leader of a country is changed (or a leader from a different political party or group, in contrast to the previous leader, is elected), and a major nuclear accident occurred.

Our results underscore that the political, supply dynamics, and energy security environment is also entangled in the suspension of NPP deployment. The results of this study provide valuable insights into the factors that drive the decision-making process of countries in developing NPPs. The findings also contribute to the existing literature on the development of nuclear power in NEN countries.

The remainder of the paper is organized as follows. Section 2 presents a literature review on nuclear energy development and shows the main hypotheses proposed based on the review. Section 3 describes the empirical analysis strategy and specifications, and Section 4 provides the results of the empirical analyses. Section 5 presents a discussion with other empirical analyses to check the robustness. Finally, Section 6 provides the conclusions of the study.

2. Literature review

In this section, the initial review is on the literature on the determinants related to nuclear power programs, specifically their success. The literature review section is divided into multiple subsections: socio-economic and political environment, nuclear accidents, and supply dynamics. Subsequently, the main hypotheses of this study are discussed to answer the questions raised in the introduction section: (1) why do NEN countries maintain scrapping, suspension, or deferral positions of their nuclear power deployment plans after making initial efforts? And (2) why do NEN countries decide to scrap, suspend, or defer their nuclear power deployment plans after making initial efforts?

2.1. Socio-economic and political environment

It is widely known that although NPPs can have lower marginal operating costs than coal- and gas-fired plants in the long run, they are generally more expensive to construct. Therefore, financial stability is crucial for introducing nuclear power to a country. Many previous studies have established national economic size as a strong predictor of the success of nuclear power programs. Thurner et al. [8] discovered that the stronger a country's economy, the quicker a reactor project is completed. Csereklyei et al. [9] also corroborated that economic growth speeds up reactor construction. Fuhrmann [4], Gourley and Stulberg [10], and Brutschin et al. [6] have demonstrated through statistical analysis that larger economies have a higher probability of reactor construction and its connection to an electrical grid.

However, there is still a debate among many scholars as to whether democratic countries are less successful in building NPPs or do not have any specific impact compared to autocracy. Gourley and Stulberg [10] and Brutschin et al. [6] did not find the level of democracy affects whether a country starts NPP construction or adopts nuclear technology. Also, Thurner et al. [8] found that there is no significant difference between autocracy and democracy in the duration of NPP construction. However, a recent study by Neumann et al. [11] found that countries with lower levels of democratic countries are more likely to introduce nuclear power.

The decision to halt a country's nuclear power program is not solely determined by the political regime but can also heavily be influenced by the government's political party and change of leadership. Several studies have revealed that in countries such as the European Union [12], South Korea [13], and the United States [14], public preferences for nuclear energy vary based on the political party that the public supports. As public attitudes towards nuclear energy may rely on political reasoning, debates on nuclear power programs can gain significant public support when a leader from a different political party than the former leader is elected. For example, in 2017, former South Korean President Moon Jae-In temporarily suspended the construction of two NPPs under construction, after his election. This decision was due to safety concerns, but later decided to resume construction after a national deliberation process [13]. Although South Korea already had multiple NPPs under operation, this historical event shows that a change in leadership in one country can have a significant impact on the deferral of many nuclear power development plans.

2.2. Energy demand and security environment

Another main motivation for interpreting the success of nuclear power programs in the previous literature is to meet a country's growing energy needs and enhance energy security. Historical trends reveal that nuclear power has typically been introduced in response to surging electricity demands [7,15]. For instance, Cherp et al. [16] noted that the expansion of nuclear power in Japan during the 1990s was largely driven by rapid growth in electricity demand. Similarly, Brutschin et al. [6] demonstrated that high growth in electricity demand has a significant effect on the successful adoption of nuclear technology in a country and suggested that the lower electricity demand growth in some countries in the early 1990s is a reason for their slow adoption.

In addition, the adoption of nuclear energy programs is also linked to a country's energy security concerns. Empirical analyses by Fuhrmann [4] showed that the construction of NPPs is often motivated by innocuous reasons such as the need to enhance energy security. Brutschin et al. [6] demonstrated that the introduction of nuclear power in a country is consistently linked to energy import dependence, with the success of NPPs often driven by a reduction in imported fuels such as oil.

The price of oil and the emergence of alternative energy technologies such as solar and wind power can also impact nuclear power generation. When nuclear power technology was first introduced, global electricity production was largely dominated by hydropower, coal, and oil-fired generation. Therefore, it is less likely for fossil fuel-exporting countries to adopt nuclear energy technology [6]. However, some developed countries have opted for expanding nuclear energy as a replacement for imported oil in response to increasing oil prices [17]. Furthermore, Csereklyei et al. [9] found that the construction of NPPs is accelerated by the rising prices of oil. Regarding alternative renewable energy technologies, Brutschin et al. [6] observed mixed results regarding the effects of the share of renewables in nuclear power adoption/construction. While they identified a positive and statistically significant share of gas, wind, and solar energy in electricity generation when considering the dependent variable of NPP construction, they did not confirm significant evidence when using the electric grid connection of NPPs as a dependent variable.

2.3. Supply side: military alliances with major nuclear supplier countries

Like the other technologies, nuclear energy was first introduced or developed by major nuclear exporting countries (such as the United States, Soviet Union, United Kingdom, and Canada), and then adopted by latecomer countries, which are sometimes also called peripheral countries. Nuclear technology is particularly reliant on international cooperation, as it involves not only the supply of nuclear reactors but also the building of human infrastructure capacity [18]. In the case of civilian nuclear cooperation, Fuhrmann [19] analyzed over 2000 bilateral nuclear cooperation agreements between countries from 1950 to 2000, revealing that nuclear cooperation (including the construction of NPPs) is more likely to occur when both the supplier and the client countries promise to defend each other in the event of a military attack (defense pact). Another study also considered geographical and geopolitical proximity to early adopters of the technology as an important variable in shaping its diffusion [6].

However, Fuhrmann [4] found no evidence to suggest that defense pacts with the major nuclear exporting countries play a significant impact on constructing NPPs in countries. He explained that this result may be due to some countries that frequently build NPPs being major early adopters and not necessarily require foreign support to develop their nuclear power programs. He did, however, discover evidence of a relationship between NPP construction and the defense pact with major nuclear suppliers in excluded samples from the estimated population of major nuclear suppliers' observations. Therefore, having military alliances with major nuclear supplier countries can play a significant role in NEN countries to adopt nuclear energy technology.

2.4. Nuclear accidents

Nuclear accidents have been identified in some studies as a significant factor that consistently undermines the success of NPP programs. Gourley and Stulberg [10] have discovered that there is a statistically significant impact of Three Mile Island (TMI) and Chernobyl nuclear accidents on the construction of NPPs. According to Fuhrmann's [4] statistical analyses, he argued that major nuclear accidents generally decrease the likelihood of constructing NPPs in all countries. He specifically found that the effect of each major nuclear accident on the construction of NPPs varied depending on the regime type of countries and whether they already had an operational NPP. For example, he stated that highly authoritarian countries were less affected by the Chernobyl accident than highly democratic countries in terms of their construction of NPPs. Furthermore, the TMI accident was identified as a significant variable in suppressing nuclear power construction in countries where one or more NPPs were in operation at the time of the accident. The Chernobyl accident was found to be an obstacle to the construction of NPPs in countries without NPPs. Csereklyei et al. [20] also presented evidence of the adverse impacts of the Chernobyl accidents on the construction of NPPs in the global market.

However, there are some studies, albeit few, that have not found nuclear accidents to be a significant factor in hindering success. For example, Brutschin et al. [6] revealed that major nuclear accidents do not consistently play a crucial impact on adopting nuclear power in more countries.

2.5. Main hypotheses in this study from the previous literature

The common questions from previous literature, mentioned in this section, aim to determine what influences the construction and connection of NPPs to an electrical grid. However, this paper tries to re-investigate the significance of various socio-economic, political factors, and energy security environments, which have been found to be crucial in previous studies in determining a country's success in implementing a civilian nuclear energy program, as well as in the suspension, deferral, or scrapping of such a program. It is uncertain whether these factors mentioned in the aforementioned literature will consistently have the opposite effect when NEN countries, that have previously expressed interest in nuclear power programs, abandon or postpone them. Therefore, this study examines whether factors such as low economic development, high energy security, a high level of democracy, leadership change, major nuclear accidents, low oil prices, and high renewable generation positively influence a country's suspension or deferral of nuclear power program deployment.

In summary, Table 1 presents the five main mechanisms hypothesized in this study that could impact the suspension, scrapping, and deferral of nuclear power programs in NEN countries, according to the preceding sub-sections.

3. Empirical design and strategy

3.1. Research design

To answer the questions raised in the Introduction section, an initial examination was made on the historical timelines of countries' nuclear power programs from 1960 to 2020. Through this analysis, countries were identified that have only expressed interest in deploying NPPs or have shown interest or started construction, but ultimately have no NPPs operational by 2020. The above 180 literature sources were reviewed, including news items, articles, papers, and reports, to determine when countries expressed interest, suspended, scrapped, or

Table 1
Main hypotheses of our analyses.

Category	Variables	Hypotheses on the effect on NEN countries (1) maintaining scrapping, suspension, or deferral positions of nuclear power development plans or (2) deciding to scrap, suspend, or defer their nuclear power development plans after making initial efforts
Political	High level of democracy	Positive (more likely)
	Leadership change	Uncertain since this variable was not discussed well in the previous studies
Economic	High Gross Domestic Product (GDP)	Negative (less likely)
Energy demand side	High energy demand	Negative
Energy security environment	High energy import	Negative
	High renewable capacity	Insignificant or positive
	High oil price	Negative
Supply side	Defense pact with major nuclear supplier countries	Insignificant or negative
Nuclear accidents	Major nuclear accident	Positive

deferred their nuclear power programs.

Next, a time-series cross-sectional dataset was created that includes information about countries without commercial NPPs, but interested in them, or under construction, covering the period from 1960 to 2020. The unit of observation in the dataset is country-year. The dataset covers 51 countries that met the study criteria.

3.2. Empirical analysis strategy – dependent variables

The objective of this study is to identify the factors that have influenced the decision 1) to either maintain the scrapping, suspension, or deferral positions of nuclear power development plans, and 2) to halt, scrap, or defer the nuclear power program after making initial efforts. To achieve this, a binary dependent variable was assigned to each data point, with "Deferral/Scrapping/Suspension" coded as 1 (see Table 2). Each country-year observation unit in our dataset starts when a country expresses interest in developing a nuclear power development plan.

Table 2
Description of dependent variable coding.

Variable	Description
Interest	Countries become interested in developing NPPs. To be specific, the countries have received nuclear cooperation related power generation. The category of this variable is as follows: • First nuclear cooperation regarding electricity generation • Public official statement on the NPP interest • Call for vendors/tenders for deploying NPPs • Sites selection process initiation for deploying nuclear energy • Signed contract for construction • Government's projection of future electricity source from nuclear • Infrastructure review mission for large commercial power reactor by International Atomic Energy Agency (IAEA) • Restarting nuclear program/construction of NPPs • Listing nuclear power as a part of national development plan/energy mix • Construction of NPPs (only for North Korea, Philippines, Poland, Austria, and Cuba)
Deferral/Suspension/ Scrapping	Public statement of the country that scrapped, suspended, or deferred the construction of nuclear power plant or planning of nuclear power deployment.

However, two different empirical specifications were constructed (called Case 1 and Case 2), which differ in how the dependent variable is defined. Table 3 summarizes the differences. Case 1 is focused on analyzing the factors that lead to maintaining scrapping, suspension, or deferral positions of a nuclear power development plan in a country that had previously shown interest in nuclear power, until they regain interest. In Case 2, the declaration of the scrapping, suspension, or deferral itself was examined, focusing only on the year in which a country interested in nuclear power decided to suspend, scrap, or defer its nuclear power program plans.

For example, suppose that Country A first expressed interest in building an NPP in 1980, but abandoned/deferred the plan in 1985. Country A's interest was later rekindled in 2000 and has been maintained since then. In Case 1, the data tracking for Country A starts from 1980. The observation data was coded from 1980 to 1984 as 0, and from 1985 to 2000 as 1. The data from 2000 to 2020 was coded as 0 again. In Case 2, again the tracking of Country A's data is carried out from 1980, but this time the coding of the observation data from 1980 to 1984 is 0, 1985 is 1, and from 1986 to 2020 as 0 again.

The differences between Case 1 and Case 2 allowed us to address different research questions raised in this study. While the former case is to answer the question of why countries keep nuclear power deployment projects deferred, scrapped, and suspended, the latter case focuses more on the year of scrapping, suspension, or deferral of a nuclear construction project to see which variables affect the program suspension/ deferral itself.

3.3. Empirical analysis strategy – independent variables

To examine what factors have affected the countries to scrap the nuclear power development in their countries, a total of 11 variables were considered, some of which are found to be significant factors in the related literature review discussed in Section 2. The independent variables consist of six major categories: economic capacity, political environment, energy demand side, energy security environment, nuclear accidents, and supply side. The description and sources of each independent variable are shown in Table 4.

3.4. Estimation model

Since the dependent variables have two categories, a logistic regression was used to estimate the causal relationship between the independent variables and dependent variables.

$$\text{Log}\left(\frac{p_{i,t}}{1-p_{i,t}}\right) = \beta_0 + \beta_1 X_{i,t} (\textit{in Models } 1 \textit{ and } 3) \tag{1}$$

As can be seen in eq. (1), for each country-year (denoted as i and t, respectively) observation unit, $p_{i,t}$ is the probability that the dependent variable is 1, which can vary across different cases. $\text{Log}\left(\frac{p_{i,t}}{1-p_{i,t}}\right)$

Table 3
Case specifications.

Case	Case 1	Case 2
Objective	To determine why NEN countries maintain the scrapping, suspension, or deferral of nuclear power development plans	To see why NEN countries suspend, scrap, or defer the nuclear power development plans
Description	1: Between the year when a country announced the scrapping, suspension, or deferral of its NPP program and the year when it expressed interest again 0: Shows interest	1: Only the year when a country scrapped, suspended, or deferred the nuclear power development plans 0: Otherwise

Table 4
Independent variable description.

Category	Variables	Operationalization	Note/Sources
Economic capacity	GDP	Numerical: logarithmic of GDP each year	[21,22]
Political environment	Democracy	Binary: 1 if the Polity score is same or above 7 each year	[23]
	Leadership change	Binary: 1 if the leader in a country is changed each year	[24]
Energy demand side	Electricity growth	Binary: 1 if the electricity output growth (%) from the last year of a country exceeds 10% each year	Electric output data was obtained from [25,26]
Energy security environment	Crude oil price	Numerical: Historical crude oil price each year	[27]
	Oil producer	Binary: 1 if the oil rents exceed 10% of GDP each year	[21]
	Energy import	Binary: 1 if the percentage value of a country's net energy imports (imports-exports) as a portion of its total energy consumption is over 25%, and 0 otherwise	[21]/The operationalization is obtained from [6]
	Renewable capacity	Numerical: Electricity generation from renewables each year in the unit of billion kWh	[28]
Nuclear accidents	Major nuclear accident	Binary: 1 in the year of the nuclear accidents at TMI (1979), Chernobyl (1986), and Fukushima (2011) and the two consecutive years following, respectively, and 0 otherwise	To capture common time shock
Supply side	Defense pact	Binary: 1 if the country shares defense pacts with major suppliers of NPPs (Canada, France, Russia, the United Kingdom, and the United States), and 0 otherwise.	[29]/Version 4.1
	Soviet Union dissolution	Binary: 1 in the year of Soviet Union dissolution and the two consecutive years following, and 0 otherwise	To capture common time shock

corresponds to the log-odds. β_0 denotes the coefficient of the intercept term, while $X_{i,t}$ represents the column vector of the country-year observation unit's independent variables, which differ across different models. β_1 is the coefficient row vector of $X_{i,t}$.

We tested four different sets of independent variables in this analysis, referred to as Models 1–4. In Model 1, a total of seven variables were used. Model 3 includes four energy security environment-related variables in addition to the variables used in Model 1. The division between Models 1 and 3 is due to the limited availability of energy-related variables, with some countries lacking data and some energy security variables only having data from 1965 to 2014.

$$\text{Log}\left(\frac{p_{i,t}}{1-p_{i,t}}\right) = \beta_0 + \beta_1 X_{i,t} + \eta_i (\textit{in Models 2 and 4}) \tag{2}$$

The country fixed effects were also employed in logistic regression analyses in Model 2 and Model 4. The country fixed effects control for potentially confounding variables that vary across countries but are independent of time. Including country fixed effects allows for the estimation of the relationship between the variables of interest and their variations within individual countries over time. In that sense, in Model 2, country dummy variables (denoted as η_i in eq. (2)) were employed in addition to the variables used in Model 1. Similarly, in Model 4, country dummy variables were used along with variables used in Model 3. Time fixed effects were not incorporated in our analyses, which control potential confounding variables that affect all countries similarly over time. This is because effects such as major nuclear accidents and the Soviet Union dissolution independent variables, which are considered common time shocks in previous literature, were already included as independent variables.

4. Results

In Case 1, Models 1 to 4 were developed to examine the factors that influence the country's maintaining scrapping, suspension, or deferral positions of nuclear power development plans. Model 1, which is the base specification, includes variables such as economics, politics, energy demand, military alliances with major nuclear exporters, and nuclear accidents. In Model 2, country fixed effects are employed from Model 1. Model 3 includes energy security-related variables, but the number of observation units used in the analysis is reduced due to the lack of availability of some values. Model 4 includes the variables used in Model 3 and country fixed effects. The statistical results are shown in Table 5.

The results of the analysis first show that the energy security variables and the nuclear accident variable are consistently revealed as significant factors in Models 3 and 4. Specifically, a lower increase in energy demand, an occurrence of nuclear accidents, and a lower price of oil are related to a country's continued positions to scrapping, suspension, or deferral of nuclear power programs. In Model 3 and Model 4, it can also be noted that a country having high energy imports is less likely to maintain scrapping, suspension, or deferral positions of nuclear power programs. The GDP, although not robust throughout all models, has a positive significance.

The results of the analysis also indicate that the level of democracy, and a defense pact with major nuclear exporting countries are found to be significant in Model 1 and Model 3, which do not include fixed country effects, but become insignificant in Model 2 and Model 4, which

Table 5
Results of Case 1.

	Dependent variable:			
	Model (1)	(2)	(3)	(4)
GDP	0.046	1.402***	−0.247	1.850*
	(0.128)	(0.338)	(0.184)	(0.941)
Democracy	1.050***	0.135	1.851***	0.094
	(0.128)	(0.240)	(0.215)	(0.395)
Electricity growth	−0.480***	−0.684***	−0.472**	−0.553*
	(0.133)	(0.173)	(0.174)	(0.262)
Crude oil price			−0.014***	−0.023***
			(0.002)	(0.005)
Oil producer			−0.029	0.506
			(0.192)	(0.432)
Energy import			−0.741***	−3.533**
			(0.164)	(1.229)
Renewable capacity			−0.023	−0.062
			(0.014)	(0.045)
Leadership change	−0.136	−0.028	−0.326	−0.309
	(0.146)	(0.182)	(0.192)	(0.280)
Major nuclear accident	0.362**	0.588***	0.382*	0.675*
	(0.137)	(0.173)	(0.177)	(0.275)
Defense pact	−0.389***	−0.278	−0.720***	−0.874
	(0.118)	(0.244)	(0.168)	(0.462)
Soviet Union dissolution	0.750**	1.101***	0.120	0.317
	(0.243)	(0.297)	(0.267)	(0.370)
Constant	−0.929	−15.403***	3.404	−15.706
	(1.398)	(3.634)	(1.988)	(10.030)
Observations	1573	1573	1051	1051
Log Likelihood	−1022.343	−732.099	−642.298	−346.997
Akaike Inf. Crit.	2060.686	1580.198	1308.596	809.994

Note: *p < 0.05 **p < 0.01 ***p < 0.001.

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include fixed country effects. The reason for the insignificance of variables such as democracy, and defense pact with major nuclear exporting countries in Models 2 and Model 4 is that they are typically time-invariant, and their values do not usually change within each country over time. This leads to a high correlation with country dummy variables when country fixed effects are included in the model. Consequently, the coefficients of these variables become statistically insignificant, absorbed by the fixed effects.

This lower statistical significance does not mean that these variables (democracy, and defense pact) are not important in explaining the variation in the dependent variable across countries. In that sense, the results could show that democratic countries and countries lacking military alliances with major nuclear supplier countries are likely to maintain scrapping, suspension, or deferral positions on nuclear power programs.

Lastly, it is also found that the other energy security variables (electricity growth, crude oil price, and energy import) remain significant even when country fixed effects are employed, which shows that these variables are consistently significant even after controlling for country time-invariant factors.

In Case 2, logistic regression analysis was conducted using a coding scheme where only the year of scrapping, suspension, or deferral of the nuclear power program was coded as 1. This case is to see which factors are crucial in affecting a country's decision on the scrapping/suspension/deferral of nuclear power programs.

Notably, the results from Case 2 (see Table 6) differ significantly from those of Case 1. Whereas the nuclear accident variable is identified as an important factor in both cases, other independent variables previously found to be significant in Case 1, such as energy import, democracy, or military alliances with major nuclear exporters in Case 1 do not show significant effects in Case 2. However, it is worth noting that a change in national leadership is a consistently significant factor in the decision to scrap, suspend, or defer a country's nuclear power programs for NEN countries. The results indicate that when an NEN country undergoes a change in administration, it is more likely to scrap the nuclear power program that was initiated by the predecessor administrations.

Table 6
Results of Case 2.

	Dependent variable:			
	Model (1)	(2)	(3)	(4)
GDP	0.473	0.108	0.848*	1.172
	(0.244)	(0.542)	(0.368)	(1.580)
Democracy	−0.298	−0.128	−0.384	−0.493
	(0.241)	(0.434)	(0.392)	(0.697)
Electricity growth	0.024	−0.047	−0.359	−0.329
	(0.246)	(0.282)	(0.353)	(0.408)
Crude oil price			−0.005	−0.001
			(0.004)	(0.008)
Oil producer			0.597	0.431
			(0.358)	(0.715)
Energy import			0.223	1.391
			(0.331)	(0.884)
Renewable capacity			−0.035	−0.037
			(0.031)	(0.046)
Leadership change	0.571*	0.734**	0.574	0.825*
	(0.243)	(0.266)	(0.325)	(0.375)
Major nuclear accident	0.848***	0.952***	1.089***	1.121**
	(0.218)	(0.234)	(0.288)	(0.367)
Defense pact	−0.107	0.641	−0.097	1.429
	(0.225)	(0.442)	(0.316)	(0.881)
Soviet Union dissolution	−0.135	−0.299	0.032	−0.073
	(0.529)	(0.561)	(0.554)	(0.610)
Constant	−7.973**	−4.493	−12.160**	−17.098
	(2.694)	(5.867)	(4.021)	(16.836)
Observations	1573	1573	1051	1051
Log Likelihood	−386.444	−333.902	−237.900	−193.639
Akaike Inf. Crit.	788.887	783.805	499.800	503.278

Note: *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$.

Figs. 1 and 2 show the odds ratio, which refers to the $\frac{p_{i,t}}{1-p_{i,t}}$ of the significant factors in Case 1 (Fig. 1(a) and (b)) and Case 2 (Fig. 2 (a) and 2(b)) with 95% confidence intervals. For the energy import variable of Model 4 in Case 1 (see Fig. 1(b)), the odds of a country maintaining scrapping, suspension, or deferral positions of nuclear power programs decrease by a factor of 0.03 when the country's net energy imports are over 25% of its total energy consumption.

Regarding the nuclear accident variable in Case 1, the odds of maintaining scrapped, suspended, or deferred nuclear power programs are 1.44–1.96 times higher for countries that have experienced nuclear accidents in that year compared to the other years, all else being equal in the logistic regression model. We also find a significant effect of crude oil price, electricity growth, and defense pacts on the odds ratio in this graph. Also, surprisingly, the odds ratio of GDP in Case 1 is 4.06 in Model 2 and 6.36 in Model 4, which indicates that for every one-unit increase in GDP, the odds of maintaining scrapped, suspended, or deferred nuclear power program once it is discontinued are about four to six times higher, assuming all other variables remain constant.

The odds ratios for democracy in Model 1 and Model 3 of Case 1 are 2.86 and 6.37 respectively, indicating that the odds ratio is about three to six times higher for democratic countries than non-democratic countries. However, when employing country fixed effects in Model 2 and Model 4, the significance of the democracy variable disappeared, suggesting that the effect of democracy on maintaining scrapping, suspension, or deferral positions of nuclear power programs may be confounded by country-level factors that are constant over time. With that said, the significant odds ratio in Model 1 and Model 3 suggests that democratic institutions may play a role in delaying a country's decision from showing interest again in nuclear power programs.

Fig. 2 (a) and Fig. 2 (b) show the odds ratios of the leadership change variable, which is found to be crucial in Case 2. The odds ratio of leadership change from Model 1 to Model 4 in Case 2 indicates that countries experiencing a change in leadership are roughly two times more likely to announce a suspension or deferral of nuclear power programs compared to countries without any changes. To be specific, in Model 4 of Case 2, the odds ratio increased to 2.28, which suggests that the effect of leader change on the suspension or deferral of nuclear power programs is even stronger when controlling time-invariant cofounders using country fixed effects.

5. Robustness check and discussions

5.1. Robustness check – leadership change

In Case 2, the significance of the leadership change on suspension or deferral of nuclear power programs is highlighted. However, the independent variable of leadership change has a limitation as it cannot differentiate between transitions where a new leader relies on dissimilar societal/political groups compared to their predecessor and transitions where both leaders depend on identical political groups or parties.

To address this, the leadership change variable was substituted with the Change in Source of Leader Support (CHISOLS) variable, created by Mattes et al. [30], which captures whether there is a change in the source of leader support during the country-year when the new source of leader support remains in power for more than 30 consecutive days. This new variable, coded as 1, captures instances of a leader transition in which a new leader assumes office with the support of a distinct social group compared to their predecessor. On the other hand, a value of 0 represents cases without a leader transition or situations where both the current leader and their predecessor rely on essentially the same group for support. Consequently, this variable has the potential to

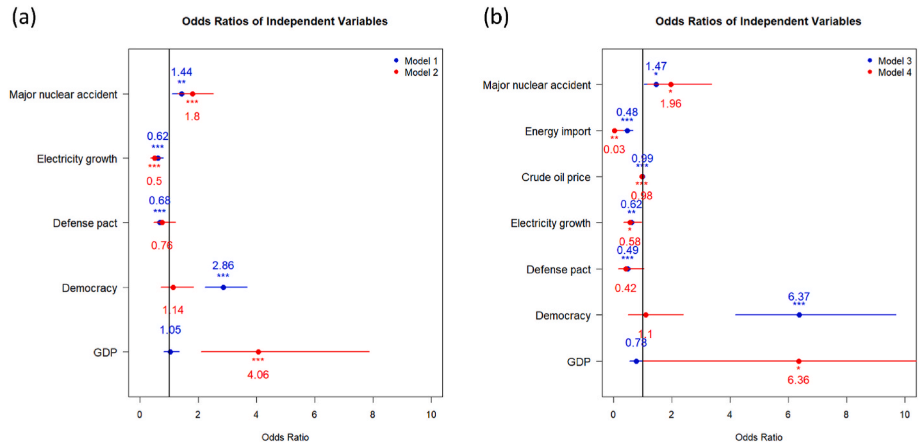

Fig. 1. Odds ratio of each model and case: (a) Model 1 and Model 2 in Case 1, (b) Model 3 and Model 4 in Case 1.

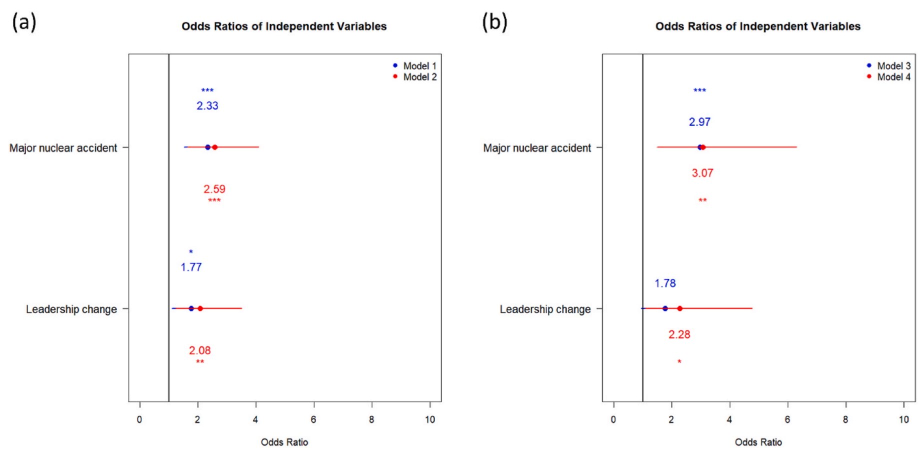

Fig. 2. Odds ratio of each model and case: (a) Model 1 and Model 2 in Case 2, and (b) Model 3 and Model 4 in Case 2.

elucidate the impact of various societal groups' support within a country on decisions related to the scrapping, suspension, or deferral of nuclear power programs.

In this analysis, Model 1 to Model 4 were used again, the same as Case 2 in the Results section. Table A 1 presents the regression results. We can observe that the sign and significance of the regression coefficients for CHISOLS are stable and like those of the leadership change variable in Case 2.

5.2. Discussions on the empirical results

Considering the nature of adopting nuclear technology, it is generally agreed that the development of nuclear energy programs is more politically driven than other energy technologies. Existing literature suggests that the success of nuclear development is due to a combination of social, technological, economic, and political mechanisms. Previous study indicates that the key social-technological mechanism of a country's nuclear development, the diffusion of technology from the core to the periphery, forms a broad pattern of transitions, while the economic and political context defines the speed and depth of the effort in acquiring nuclear technology [6].

The analyses of this study focused on why countries that were interested in nuclear power have scrapped, suspended, or deferred their nuclear power programs, in contrast to existing literature. As a result, our main hypothesis is that many of the factors that have contributed to the success of nuclear construction and power production in previous studies (i.e., socio-political, and economic factors) have also played a significant role in deferring nuclear development plans for countries that were interested in nuclear power, but in the opposite direction.

The summary of the findings from this study is as follows. Firstly, the positive significance of GDP in the results, although not robust, suggests that NEN countries with higher GDP are more likely to scrap, suspend, or defer their nuclear power programs, and maintain their positions during the given period. The results contradict our hypothesis described in Section 2.5 (see Table 1). However, it is important to note that the relationship between GDP and the dependent variable may be influenced by other country-specific factors, data overestimation, and historical timelines.

This study specifically focused on NEN countries, excluding country-year data points of established nuclear energy countries with high economic capacity. By excluding such countries, a significant proportion of high-GDP countries has inadvertently been removed from the sample. This may have resulted in an overestimation of the positive association between GDP and the dependent variable, making it challenging to detect a significant effect of GDP on the outcome variable when country fixed effects are applied in Case 2.

Additionally, in Case 1, several countries with higher GDP than others in the dataset have chosen to abandon their nuclear power programs and have persisted with that position. Notably, Austria, Ireland, Norway, and Denmark serve as prime examples. These countries have never had operational NPPs and have still taken a firm stance against nuclear energy, instead actively pursuing renewable energy sources (i.e., hydropower for Austria and Norway, wind power for Ireland, Norway, and Denmark) to meet their energy needs. Austria, for instance, prohibited the use of nuclear power in 1978 through a national referendum [31], while Denmark has long-standing policies in place to prevent the construction of NPPs.

Furthermore, it is possible that the positive significance of GDP in the analysis captures some of the variation related to the more than 20 countries that scrapped, suspended, or deferred their nuclear power programs in the 2010s after the Fukushima accidents (see Table 7). This is because GDP tends to increase over time due to factors such as population growth, technological advancements, and economic policies. In summary, countries with higher GDP may have more resources to invest in alternative energy sources or delay the implementation of certain plans, affecting the likelihood of deferring or suspending plans. However, it is important to consider that other factors may also influence the decision to defer plans, and disentangling the effect of GDP from these other factors is challenging.

Study results also suggest that countries with higher levels of democratic development are more likely to maintain scrapping, suspension, and deferral positions on nuclear power programs, which supports our hypothesis (see Table 1). This result is also consistent with the previous literature which suggests that NPP construction is more likely in countries with lower levels of democracy [5]. Based on this literature, it can be inferred that the level of democracy in a country could also impact the suspension and deferral positions of nuclear power development plans in the opposite direction.

The lack of military alliance of major technology suppliers (i.e., the United States, United Kingdom, Soviet Union, France, and Canada) is found to deter a country's regaining interests in NPP deployments. This is consistent with Fuhrmann's [19] study, which examines the relationship between nuclear cooperation and military alliances. Fuhrmann [19] found that a strong military alliance increases the probability of countries signing a comprehensive nuclear power agreement which represents the nuclear power programs for producing electricity. As such, it can be also interpreted that if a country is interested in a nuclear power program but lacks a military alliance with a major nuclear exporting country, it may be even more inclined to maintain the suspension or deferral of the program since there are no strongly supportive major nuclear supplier countries to deploy nuclear power program.

This study consistently underscores that the main reason many countries maintain the scrapping, suspension, or deferral positions of NPP deployment is not only due to their national energy security situation, but also to relatively lower electricity demand growth. This finding is in line with previous studies, which suggest that NPP construction is more likely in countries with lower energy security [4,6] and high electricity demand [6]. This study reaffirms that the factors deemed significant for the success of nuclear power plant deployment can also impact the failure of a country's adoption of nuclear power programs in the opposite direction. Specifically, the findings of this study suggest that when a country's energy demand growth is not high enough, when they have relatively good energy security, or when the oil price is relatively low, there may be a delay in rekindling interests in nuclear power development plans once they have been put on hold.

Lastly, the failure of the nuclear power deployment plans can be largely attributed to changes in the country's administration, specifically leadership transitions. This is evident in cases where new leaders assume office with the support of different social or political groups than their predecessors. This is a new argument, which was not well discussed in previous studies. This argument is supported by the historical evidence of some countries. For example, in Greece, an earthquake struck near Athens in February 1981, but the ruling party at the time continued to support the plant. However, in October of that year, the populist socialist party PASOK won the election, and Prime Minister Andreas Papandreou reversed course and announced that he would not support any NPP [32]. Another example can be found in the Philippines. After taking office in 1986, Philippine President Corazon Aquino abandoned plans to pursue the nuclear power program and decided against the operation of the Bataan NPP, which had been built during the administration of former President Ferdinand Marcos, in the aftermath of the Chernobyl disaster that occurred the same year [33]. Regarding Poland, Lech Wałęsa was elected as President in December 1990, after the decision to halt the Żarnowiec project had already been made on September 4, 1990. However, he was involved in political and social movements against the construction of the NPP and publicly voted against it in the referendum, where residents of the Gdańsk region were asked to express their opinion on the construction of an NPP in Żarnowiec [34]. Although the government was not legally obligated to follow the referendum results, the strong opposition to the construction of the NPP expressed by 86% of the population in the referendum had a significant impact on the government's decision-making process.

Table 7
The year when the country pronounced to halt, suspend, or defer its nuclear power program following the Fukushima disaster.

Countries	Year
Algeria	2013
Bahrain	2012, 2015
Chile	2012
Ecuador	2011
Indonesia	2017
Israel	2011
Jordan	2018
Kazakhstan	2016
Kenya	2020
Kuwait	2011
Malaysia	2011, 2013, 2016, 2018
Myanmar	2013
Namibia	2011
Oman	2011
Peru	2011, 2016, 2018
Poland	2012
Portugal	2016
Saudi Arabia	2011, 2015
Singapore	2018
Sudan	2019
Thailand	2011, 2015
Vietnam	2014, 2016

5.3. *Limitations of the study*

This study analyzed conceptually the technology-specific and context-specific factors separately as independent variables. However, in practice, there may be strong interactions or causal relationships between the two independent variables, which were not accounted for. In this study, variables that are difficult to measure consistently across many countries over a long period of time were not fully captured, although country fixed effects were considered. For example, public preference or non-preference for nuclear power may have a significant impact on nuclear power failures in countries interested in nuclear power, but data on this variable is sparse. This study did not explore the role of leaders' political leanings or preference for nuclear energy in the analysis, which can be critical in the decision of nuclear power programs. Finally, the study dataset is limited to the countries that do not operate NPPs by 2020, but even in countries that do have NPPs, there is stagnation and decline of nuclear power in some of these countries. Many nuclear energy established countries have had experience with reversing or postponing new NPP programs even though they have NPPs. It would be meaningful to include these countries in the following research.

6. Conclusions

Given the recent rise in the number of countries interested in nuclear energy, the aim of this study was to understand many of the backgrounds and motivations behind the adoption of nuclear power technology in many countries. In this context, the study focused on nuclear power program deferrals and suspensions, as there is a rich literature and academic debate on the causes of successful nuclear power program deployment. The research design adopted has two unique features with respect to work on nuclear power program deferrals or suspensions. First, the empirical analysis was limited to countries that do not have commercial NPPs and were interested in, or at least have scrapped, suspended, or deferred nuclear power programs. Then the analysis was carried out to determine whether the variables found to be significant in the existing literature are also crucial for the current study.

The main lesson learned from the empirical analysis is that the primary motivations for suspending a nuclear power program can be explained by a complex mechanism of socio-political environment, energy security, major nuclear accidents, and military alliances with major nuclear export countries. The results of the study suggested that leadership changes and major nuclear accidents are important for decisions on suspending or deferring a nuclear power program. Furthermore, the study showed that a country's energy security, socio-political environment, and military alliances are critical for maintaining scrapping, suspension, or deferral positions on this issue.

For the future success of peaceful NPP deployment in NEN countries, our policy implications are as follows. First, a country must ensure that the plan for NPP development is not significantly affected by changes in leadership. Moreover, countries that export nuclear power technology should prioritize the development of safer NPPs. Countries with existing NPPs should also closely monitor their operations to minimize the occurrence of major nuclear accidents. This will help to prevent other NEN countries from abandoning their nuclear power programs midway.

Despite the limitations of our study, this study provides a theory related to political, economic, and national surrounding environments by understanding the different factors that lead to the suspension and deferral of nuclear power technology adoption. It sheds light on a more granular and different perspective, namely, the impact of failure, which extends beyond the analyses of the previous studies identifying the important factors of adopting nuclear power technology. The novel analytical design used contributes to the literature on nuclear energy policy and deepens the current understanding of nuclear energy. The results of this study also have implications for the nuclear industry and policymakers for successful nuclear power development in the future.

Declaration of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table A 1
Results of the robustness analysis when replacing the leadership change variable with the CHISOLS

	Dependent variable: Model			
	(1)	(2)	(3)	(4)
GDP	0.490*	0.112	0.851*	1.219
	(0.244)	(0.540)	(0.366)	(1.601)
Democracy	−0.314	−0.194	−0.409	−0.506
	(0.244)	(0.434)	(0.390)	(0.694)
Electricity growth	0.042	−0.037	−0.346	−0.334
	(0.246)	(0.282)	(0.353)	(0.409)
Crude oil price			−0.005	−0.002
			(0.004)	(0.008)
Oil producer			0.642	0.479
			(0.361)	(0.717)
Energy import			0.226	1.421
			(0.331)	(0.888)
Renewable capacity			−0.033	−0.034
			(0.031)	(0.046)
CHISOLS	0.641*	0.815*	0.832*	1.176**
	(0.298)	(0.328)	(0.382)	(0.447)
Major nuclear accident	0.846***	0.946***	1.091***	1.142**
	(0.218)	(0.234)	(0.288)	(0.368)
Defense pact	−0.113	0.605	−0.125	1.386
	(0.225)	(0.443)	(0.316)	(0.883)
Soviet Union dissolution	−0.135	−0.252	0.035	−0.019
	(0.529)	(0.554)	(0.554)	(0.602)
Constant	−8.121**	−4.521	−12.201**	−17.595
	(2.698)	(5.837)	(4.004)	(17.069)
Observations	1573	1573	1051	1051
Log Likelihood	−386.924	−334.667	−237.250	−192.754
Akaike Inf. Crit.	789.849	785.334	498.501	501.508

Note: $^{*}p < 0.05$ $^{**}p < 0.01$ $^{***}p < 0.001$.

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