Energy Research & Social Science 63 (2020) 101389

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Democratic quality and nuclear power: Reviewing the global determinants for the introduction of nuclear energy in 166 countries☆

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ARTICLE INFO

Keywords:
Nuclear power
Nuclear energy
Nuclear warhead
Democracy
Multinomial logit
Panel data

ABSTRACT

This paper analyzes the nature of democratic development in a nation on the process of introducing nuclear power over the period 1960 - 2017 for an unbalanced panel of 166 countries. Given the involved political process of introducing nuclear power and its political importance, as well as proposals to construct new nuclear reactors in currently about 30 countries, this question is both of historic and current interest. We apply a multinomial logistic regression approach that relates the likelihood of a country to introduce nuclear power to its level of democratic quality and nuclear warhead possession. The model results suggest that countries with lower levels of democratic development are more likely to introduce nuclear power. Our results moreover indicate that countries which possess at least one nuclear warhead are more likely to continue to use nuclear power instead of not using nuclear power at all. We discuss these results in the context of the public policy debate on nuclear power, yet beyond energy and environmental issues addressing the neglected political and democratic dimension in connection with nuclear power.

1. Introduction

Nuclear power was one of the most important developments of the 20th century, and it continues to affect discussions about energy security, climate change, and geopolitics well into the 21st century. Nuclear power emerged from the combination of “basic science and warfare” [1] in the 1940s. Decisions in this sector have always been based on political bargaining and state financing, rather than on pure economic rationality [2–4]. Understanding the drivers of national decisions to “go nuclear”, i.e. to bring nuclear power plants online in a country, is therefore crucial not only for interpreting the history, but also the future perspectives of nuclear technology: At the time of writing this paper, 31 countries depend on nuclear power to produce electricity, and approximately thirty more are debating, planning, or building nuclear power generation [5]. The International Atomic Energy Agency (IAEA) still considers a high global potential for nuclear power up to the year 2050 [6].

The political nature of decisions on nuclear power raises interesting questions, in particular with respect to the drivers of these decisions, the criteria for going nuclear, (or not going nuclear), and the decision-making and implementation process. The institutional and political framework of the participating actors moreover plays an important role in particular against the background of higher overnight costs of nuclear power compared to coal and natural gas [7,8]. The technical complexity of nuclear power and the need for strong vertical and horizontal coordination within the sector suggests centralized decision-making, in addition to political, cultural, and social characteristics of a country that influence nuclear trajectories [9]. In that context, the nature of the political system, e.g. the degree of democratic and competitive decision-making, can be expected to be an important variable. Socio-cultural, political and economic conditions which encourage the deployment of nuclear power, have already been acknowledged in qualitative multi-country case studies (e.g., [10,11]), yet empirical research emphasizing in particular the political economy dimension of

☆ An earlier version of this paper was presented at the Low Carbon Transformation and Sustainable Development - Status Quo and Research Outlook in Berlin in April 2018, at the 41st IAEE International Conference in Groningen in June 2018, at the Berlin Conference on Sustainable Energy and Infrastructure Economics and Policy (BELEC) in Berlin in October 2018, and at the Bavarian Berlin Energy Research (BB²) Workshop in Munich in February 2019. We thank the seminar and conference participants for fruitful discussion and input. We also thank the editor and three anonymous referees that helped to improve the quality of the paper. All remaining errors are ours.

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https://doi.org/10.1016/j.erss.2019.101389
Received 3 July 2019; Received in revised form 26 November 2019; Accepted 28 November 2019

nuclear power is surprisingly scarce.

To fill this research gap, this paper empirically analyzes the relationship between a country's decision to introduce nuclear power - defined as connecting the first nuclear power plant to the grid - and the level of democratic development. We use observable characteristics from the Power Reactor Information System (PRIS) database [12] to specify three categories which distinctively define a countries' nuclear energy strategy chosen over time. At each point in time we evaluate if countries currently use, have used at any point in time, or start to construct a nuclear power plant. Any given country which has no nuclear power plant under construction or operational at time *t* is categorized as "non-nuclear". We define the period of the construction start of the first nuclear reactor until the first grid connection of any nuclear power plant as the observable outcome to "go nuclear", which then represents the introduction of nuclear power. At any point in time countries are categorized as "nuclear" if they have at least one nuclear power reactor fully operationally at time *t*. The three distinct observable outcomes for a countries' nuclear energy strategy are operationalized as our dependent variable which is categorical and of unordered nature. We use our main predictor, the level of democratic development in both continuous and categorical modes, to measure the degree of institutionalized democracy and autocracy, respectively. We include national development, energy transitions, and environmental indicators as identified in the published literature as the explanatory variables and we also control for nuclear warhead possession.

Our initial hypothesis, based on the existing literature and the qualitative case studies from Sovacool and Valentine [10] and Valentine and Sovacool [11], is that due to the complex, and often controversial, political decisions required to develop nuclear power, less democratically governed countries are more likely to enter the sector and introduce nuclear power than countries with higher levels of democracy. We analyze the impacts of democratic development on the introduction of nuclear power from 1960 to 2017 for an unbalanced panel of 166 countries. Different from the previous literature (e.g., [13]), we focus on the motives affecting the initial introduction of nuclear power emphasizing the level of democratic development as a key determinant for the nuclear energy choice while covering a broader time frame than previously examined.

Our model is based on a multinomial logistic regression approach that relates the likelihood of a country to introduce nuclear power to its level of democratic development. The model results robustly suggest that countries with lower levels of democratic development are more likely to introduce nuclear power. Our empirical analysis thus provides a robust statistical assessment of the democracy and nuclear power nexus and identifies the variable democratic quality as an important factor to the nuclear energy choice. We contribute to the ongoing discussion about nuclear energy by shifting the focus beyond economic, climate, and environmental issues towards the frequently neglected political and democratic dimension of nuclear power. According to Gralla et al. [9], focusing on the political dimension of nuclear power is highly relevant in order to complement the global view on nuclear energy.

The remainder of this paper is organized as follows. Section 2 provides the background and reviews the empirical literature in connection with nuclear power and democracy. Section 3 presents the data and explains our empirical approach. Section 4 reports the empirical results. Section 5 presents the checks for robustness. Section 6 concludes with a discussion and offers suggestions for future research.

2. Background and related literature

This section draws on both theoretical and empirical literature to present an overview of which factors out of the political realm in particular are considered to be relevant for nuclear power development. Section 2.1 presents the theoretical underpinnings of our empirical analysis and Section 2.2 reviews related empirical applications. In general, the early literature on nuclear power uses detailed case studies to analyze how nuclear power developed in different political contexts. A more empirically orientated strand analyzes aggregate indicators which might facilitate the development of nuclear power development within a cross-country set up [14]. However, both, empirical analyses investigating the relationship between nuclear power deployment and democracy in particular, and contributions concerning more generally socioeconomic factors of nuclear power deployment are surprisingly scarce.

2.1. Theoretical underpinnings

The multi-level perspective (MLP) is a useful analytical tool to determine how a country's level of democratic development may affect the introduction of nuclear power. The MLP understands transitions as outcomes of alignment between developments at multiple levels. It consists of the three analytical levels niche-innovations, sociotechnical regimes, and sociotechnical landscapes which help explain transitions based on interactions between processes at these three levels [15]. The sociotechnical landscapes at the top level is an exogenous environment beyond the direct influence of actors within sociotechnical regimes and niche-innovations [15].

The sociotechnical regime layer contains multiple dimensions such as policy, technology, user practices, science, cultural meaning, infrastructure and industry [16]. The energy supply sector is embedded in the sociotechnical regime layer of this multi-level environment and can be conceptualized as a sociotechnical system which similarly consists of actors, institutions, as well as material artifacts and knowledge. The diverse components of the system interact, are interrelated and dependent on each other [17]. Nuclear power thus is situated in a social and political environment that influences its evolution and interacts with different socio-economic institutional settings and various stakeholders during development, construction, and operation. In this regard, large scale energy technologies are considered not as a determinant of political regimes but rather as co-evolving with a country's socio-economic institutions, actors, and social norms over the operational lifetime which usually spans over decades.[1] Conventional nuclear power plants - unlike distributed renewable energy infrastructures such as wind and solar - generate electricity on a massive scale in a centralized location. Nuclear energy consequently has found its particular niche in providing baseload electricity in the energy system [18,19]. The introduction of nuclear energy thus depends on the relationships between the three layers and the involvement of a variety of factors including policy, technology, user practices, science, cultural meaning, infrastructure, and industry. The dynamics of sociotechnical systems associated with nuclear power are related to the general political culture, elite policy discourse, patterns of public opinion and wider attributes of democratic governance which represent general qualities of democracy [20].

Democratic quality is multidimensional in nature with different aspects of democratic quality overlapping. Diamond and Morlino [21] identify eight dimensions: the rule of law; participation; competition; vertical accountability; horizontal accountability; respect for civil and political freedoms; progressive implementation of greater political (and underlying it, social and economic) equality; and responsiveness on which democracies diverge in terms of quality. The linkages among the different aspects of democracy "[...] interact and reinforce one another, ultimately converging into a system". Diamond and Morlino [21] moreover define minimum standards for democracy: universal, adult suffrage; recurring, free, competitive, and fair elections; more than one serious political party; and alternative sources of information.

[1] In the United States, some aging reactors have received lifetime extensions to 80 years. If decommissioning and long-term storage of radioactive waste management also is considered, a plant's lifetime extends to a million years.

There are no universal definitions, however, of democracy and democratic quality. Zakaria [22] defines a liberal democracy as a political system characterized by free and fair elections, the rule of law, separation of powers, and the protection of basic liberties of speech, assembly, religion, and property. The author notes that few countries characterized as falling between democratic and nondemocratic matured into liberal democracies during the 1990s. Zakaria [22] coined the term "illiberal democracy" to describe countries that have free and fair elections but "are routinely ignoring constitutional limits on their power and depriving their citizens of basic rights and freedoms". In such countries, "[a] weak rule of law will likely mean that participation by the poor and marginalized is suppressed, individual freedoms are insecure, many civic groups are unable to organize and advocate, the resourceful and well-connected are unduly favored, corruption and abuse of power run rampant, political competition is unfair, voters have a hard time holding rulers to account, and overall democratic responsiveness is gravely enfeebled" [21].

Another analytical concept related to our analysis is the framework of concentrated energy-politics vs. distributed energy-politics: the spatial distribution of energy infrastructures influences democratic development and the degree of democratic development influences the spatial distribution of energy infrastructures. According to Burke and Stephens [23], due to their inherent flexibility decentralized energy technologies are considered to more readily organize and enable distributed political and economic power, and vice versa. This relationship is characterized as strongly democratic and described as distributed energy-politics. On the contrary, energy systems based on concentrated energy sources are considered to organize and enable more concentrated forms of power and centralized or authoritarian political relationships, and vice versa. This relationship thus is characterized as weakly democratic and refers to concentrated energy-politics. To what extent political power is concentrated and democracy is developed may impact the deployment of certain energy infrastructures, but the developed energy system similarly may influence the level of democratic development. With respect to nuclear power, Bookchin [24] argues that the enhancement of democracy by decentralizing power is prevented by the continuation of nuclear energy. Lovins [25] similarly questions the democratic extension capabilities of nuclear energy as it is a "hard" centralized energy path which in part due to its inherent nuclear weapon proliferation potential affects society in terms of authoritarian forms of governance [20].

Historically, certain environments and conditions have encouraged the development of nuclear power. Sovacool and Valentine [10] and Valentine and Sovacool [11] develop a theoretical framework consisting of six influential factors: strong state involvement in guiding economic development; centralization of national energy planning; campaigns linking technological progress to national revitalization; influence of technocratic ideology on policy decisions; subordination of challenges to political authority; and low levels of civic activism.[2]

Strong centrally led economic planning and state involvement either directly through government action or indirectly through state-owned utilities is considered necessary due to the inflexibility and complexity of nuclear power and a high degree of supply chain coordination to realize such energy mega-projects. Similarly, centralization of energy planning facilitates the necessary control and enables to overcome disagreements internally which lowers transaction costs during resolution processes encouraging the expansion of nuclear power. Since nuclear power historically is associated with technological progress and modernity, governmental strategies committed to link technological developments to a national renaissance encourages a national culture which is more likely to tolerate the risks associated with nuclear power. When technocratic ideology strongly influences public policy, the necessary ideological support for nuclear power development is provided. Conditions under which political and public debate are minimized more easily enable the implementation of governmental programs which run contrary to public interest. Lastly, environments which eliminate civic activism detrimentally impact public opposition which could oppose the development of nuclear power programmes. According to Sovacool and Valentine [10] and Valentine and Sovacool [11] these six catalysts are simultaneously political, social, and economic. However, only the political environment can influence and overpower both the social and economic dimension at least in authoritarian regimes more easily. Influential factors such as strong state involvement in economic development, centralization of national energy planning, subordination of challenges to political authority, and low levels of civic activism concern the realms of democracy are in connection with rather authoritarian than democratic regime characteristics.[3]

Kitschelt [26], who compares anti-nuclear protest movements in France, Sweden, the United States, and West Germany, argues that a country's political and institutional dimensions in which social movements operate shape the level and pattern of the protests. Mobilization strategies and impacts of social movements can be explained partly by the general characteristics of political opportunity structures. In other words, the chances of broad mobilization increase when anti-nuclear movements can easily collect and disseminate information which in turn can influence policies concerning nuclear power development and expansion. Already Weinberg [27] recognizes the importance of public perception towards nuclear power: "The public perception and acceptance of nuclear energy [...] has emerged as the most critical question concerning the future of nuclear energy". O'neil [28], who analyzes the development of nuclear energy in transformation states, argues that citizens' willingness to protest may be influenced by the country's level of nuclear energy dependence, i.e., anti-nuclear movements are less likely to occur in countries with a relatively large dependence on nuclear energy due to the public's fear of higher electricity bills or fear of negative growth effects. O'neil [28] also concludes that support or opposition to nuclear power is "not a function of democracy but rather of complex relationships between state, society, and the institutions they create".

Jewell and Ates [14] emphasize the importance of political stability for both internal (program constancy and reliability) and external (investor confidence) support of nuclear power development. Jewell [29] also observes that in politically unstable countries, the introduction of nuclear power for civil purposes in conjunction with developing nuclear weapons is only possible by mobilizing extraordinary political will and resources. This logic in particular applies to countries such as India and Pakistan which both are characterized by low levels of the World Bank Political Stability Index (PSI). Both countries have experienced political instability in the years preceding or following construction of their first nuclear power plants according to the Political Instability Task Force (PITF), which records events in connection with the occurrence of "partial or total state failure".

Following World War II, nuclear power first emerges as the "child of science and warfare" [1] in the victorious countries of the USA, the USSR, the UK, and France, and later in China. Today, nuclear power sits at the intersection of military use and electricity generation. Over time, the development of atomic energy for civil purposes and for military use has become interchangeable and interdependent [30].

[2] Sovacool and Valentine [10] moreover identified the abatement of greenhouse gas emissions as a potential seventh factor emerging in the environmental policy realm.

[3] Military rule in South Korea for instance allowed the government to control the policy agenda and strong autocratic control over the economy and society until the late 1980s. In Japan, government control over the media in the 1960s and 1970s diluted political and popular opposition to nuclear power development and the dangers. In China, although environmental activists collected about one million signatures against the Daya Bay nuclear power plant, the government detained and arrested protesters [10,11].

In fact, Hirschhausen [2] argues that nuclear power has to be analyzed under the topic of joint production (so called "economies of scope") as nuclear co-production includes military goods (e.g. plutonium, tritium) as well as civilian goods and services (e.g. electricity, medical services). Related to this, Stirling and Johnstone [3] emphasize the importance of industrial supply chains involving the wider nuclear skills, education, research, design, engineering, and industrial capabilities necessary to sustain or introduce nuclear weapon programmes as well as for nuclear powered submarines capabilities.

2.2. Related empirical work

Fuhrmann [13] uses a probit model to empirically identify factors which encourage 129 countries to build nuclear power plants from 1965 to 2000. Based on information from the International Atomic Energy Agency's Power Reactor Information System (PRIS) database, the dependent variable is dichotomous and coded as 1 if a country begins building a reactor in year t +1, and 0 otherwise. As predictor variables, Fuhrmann [13] includes GDP as a proxy for economic capacity, energy dependence, an indicator for nuclear weapons exploration, a dummy variable which indicates if a state shares a defense pact with a major supplier of nuclear power plants, Nuclear Non-Proliferation Treaty (NPT) membership dummies, and nuclear accidents dummies which interact with the composite indicator from the Polity IV Project measuring a country's regime type. The empirical results indicate that higher levels of economic development are associated with a higher probability for construction and that countries which become less dependent on energy imports are less likely to build nuclear reactors. The indicator for nuclear weapons exploration, the supplier alliance dummy, and the NPT indicator are statistically insignificant. Fuhrmann [13] also shows that the impacts of nuclear accidents on construction depend on regime type, i.e., highly authoritarian states tended to be less affected by the Chernobyl disaster than countries with high levels of democratic development.

Yamamura [31], who empirically analyzes the effect of free media on the Japanese public's view of nuclear energy after the 2011 Fukushima Daiichi nuclear disaster, uses cross-sectional panel data of 37 countries collected approximately two weeks after the disaster. From the survey the author obtains the rate of agreement that nuclear power plants are properly secured against accidents and uses it as the dependent variable, controlling for the presence of nuclear power plants, freedom of expression and media, total number of natural disasters since 1970, GDP per capita, government expenditures, and including dummies for East Asian countries. The results show that freedom of expression and media significantly influences views on the security of nuclear power plants. Citizens tend to disagree that nuclear power plants are properly secured against accidents when the political setting assures both freedom of expression and media to a greater extent. The results moreover show that freedom of media leads citizens to support the presence of nuclear energy. The latter result seems to contradict our reasoning above. It however rather highlights the importance of freedom of media to be guaranteed. Only when freedom of media is guaranteed, citizens are able to evaluate costs and benefits associated with the presence of nuclear energy to then decide informed about nuclear policy [31].

Gralla et al. [9] group countries according to the nuclear energy strategies (no nuclear production, phase-out, planning to produce, produce nuclear energy) of the World Nuclear Association. Based on the statistical mean for the respective group on 20 indicators from 1960 to 2013, nuclear countries have higher per capita energy use, carbon dioxide emissions, and household final consumption expenditures compared to countries planning to use nuclear energy and countries without nuclear energy use. Gralla et al. [9] use a generalized linear mixed model (GLMM) and the nuclear energy status of all countries between 1960 and 2013 as the dependent variable to identify the socioeconomic, technological, and environmental indicators correlating with the starting year of each country's nuclear energy production. They find that 28 out of the 96 world development indicators significantly correlate with the start of nuclear energy production. Gralla et al. [9], however, do not control for the level of democratic or institutional development.

3. Data and methodology

Section 3.1 describes the three categories which define a country's nuclear energy strategy chosen over time and presents a descriptive analysis of the utilized panel dataset. Section 3.2 discusses the methodology for predicting the probability of category membership in order to analyze if democracies tend not to start constructing nuclear power plants compared to democratically less developed countries.

3.1. Data

Our analysis covers the period from 1960 to 2017 and we construct an unbalanced panel time series dataset covering 166 countries.[4] We empirically analyze how the level of democratic development impacts a countries' choice to introduce nuclear power, controlling for nuclear warhead ownership, national development, and both energy transitions as well as environmental indicators.

Our polytomous dependent variable is based on information from the Power Reactor Information System (PRIS) database [12] and contains the three categories "non-nuclear", to "go nuclear", and "nuclear" which represent the current nuclear energy statuses of a given country in a given year to establish a countries' nuclear energy strategy chosen over time. The unit of analysis thus is the country-year. The country-years take on the value zero if the respective country has no nuclear power plant under construction or operational in any given year. The period of the construction start of the first nuclear reactor until the first grid connection of any nuclear power plant is coded as one for each country-year which represents the introduction of nuclear power. Accordingly, this indicates the period of the completion of the first nuclear reactor project. Nuclear country-years are coded as two if at least one nuclear power reactor is fully operationally.[5]

Our key predictor of interest, the level of democratic development,

[4] The World Development Indicators (WDI) database from The World Bank originally includes 217 countries. The Polity IV Project data set includes only 167 countries. Therefore, we exclude the 50 countries not included in the Polity IV Project data set and also Taiwan, which is not covered in the WDI database, to obtain 166 countries. We exclude: American Samoa, Andorra, Antigua and Barbuda, Aruba, Bahamas The, Barbados, Belize, Bermuda, British Virgin Islands, Brunei Darussalam, Cayman Islands, Channel Islands, Curacao, Dominica, Faroe Islands, French Polynesia, Gibraltar, Greenland, Grenada, Guam, Hong Kong SAR China, Iceland, Isle of Man, Kiribati, Liechtenstein, Macao SAR China, Maldives, Malta, Marshall Islands, Micronesia Fed. Sts., Monaco, Nauru, New Caledonia, Northern Mariana Islands, Palau, Puerto Rico, Samoa, San Marino, Sao Tome and Principe, Seychelles, St. Maarten (Dutch part), St. Kitts and Nevis, St. Lucia, St. Martin (French part), St. Vincent and the Grenadines, Tonga, Turks and Caicos Islands, Tuvalu, Vanuatu, US Virgin Islands, and West Bank and Gaza.

[5] To define a country's nuclear energy status, we follow the literature, e.g. Jewell and Ates [14]; the International Atomic Energy Agency (IAEA) [34] uses the period after the grid connection date of a nuclear reactor as the definition. We also code the introduction of nuclear power for either the period of the construction start until the respective reactor reaches first criticality as well as until the commercial operation date. Our results, however, do not change for choosing the period until first criticality as well as until the commercial operation date (we thank an anonymous referee for raising this important issue). We moreover note that Italy started with the construction of the first nuclear reactor on 01 November 1958 which was connected to the grid on 12 May 1963. The last reactor in Italy was shut down on 01 July 1990. Kazakhstan started the construction of the first nuclear reactor on 01 October 1964 which was connected to the grid on 16 July 1973. The reactor was shut down on 22 April 1999. Lithuania started with the construction of the first nuclear reactor on 01 May 1977 which was connected to the grid on 31 December 1983. The last reactor in Lithuania however was shut down on 31 December 2009.

comes from the Polity IV Project from the Center for Systemic Peace. The index from the Polity IV Project is a combination of the institutionalized democracy and autocracy indicator. The Polity score is computed by subtracting the autocracy from the democracy score which results in an unified polity scale ranging from +10 (strongly democratic) to -10 (strongly autocratic). We use the Polity2 score which is a modified version of the Polity index to facilitate the use in time-series analyses [32]. Following Haber and Menaldo [33] we first normalize the Polity2 index to run from 0 to 100 to obtain a continuous democracy variable $D1$. To obtain a categorical measure for the democracy levels, we classify countries with a score of $D1 > 66$ as democratically free *F*, $33 < D1 < 66$ as democratically partly free *PF*, and $D1 < 33$ as democratically not free *NF* to operationalize fully liberal democratic characteristics, illiberal democratic characteristics, and non-democratic regime characteristics, respectively.[6]

The decision of a country to introduce nuclear power might partly be driven by the aim to develop nuclear weapon programmes. Nuclear reactors fueled by uranium used for generating civilian electric power accumulate plutonium. Nuclear power producing countries over time acquire enough quantities of plutonium usable for nuclear weapons [35]. It is therefore only a question of political will and willingness to develop nuclear weapons or not for nuclear power producing countries [36]. We construct an indicator *W* which takes on the value one if a country possesses at least one nuclear warhead in a given year and zero otherwise.[7] Moreover, we control for national development (GDP per capita, urbanization) and both energy transitions and environmental indicators (electric power consumption, fossil fuel rents, energy imports, CO_2 emissions per capita) from the World Development Indicators (WDI) database from The World Bank which all significantly correlate with nuclear energy production [9].

GDP per capita *GDP* is measured in constant 2010 USD and our main indicator for a countries' financial capacity. A high degree of national financial capacity for nuclear power development is necessary to allocate initial investments for creating the regulatory, legislative and basic physical infrastructure before construction, but similarly required to finance actual construction of the first nuclear power plant [29]. Urbanization *U* is measured as the share of the population living in urban areas and reflects the transition from rural to urban areas. Urbanization intensifies the demand for urban infrastructure and transportation, and stimulates the concentration of consumption and production which is associated with increasing energy demand [39]. To control for a countries' electricity demand, we use electric power consumption *E* measured in kWh per capita as an additional predictor variable. Energy security considerations can translate into motivations for pursuing nuclear energy in order to increase energy independence. In countries such as Japan, the UK, France, and Finland, independence of energy imports are main arguments for supporting nuclear power [9,29]. We use energy imports *EI* (% of primary energy use) to measure energy security and independence. In countries which are richly endowed with fossil fuels, the presence of cheap and abundant domestic fuels is expected to similarly affect a countries' energy mix and thus the likelihood for nuclear power deployment. We thus construct an indicator for fossil fuel rents *FFR* which are the sum of oil rents, natural gas rents, coal rents measured in percentage of GDP. CO_2 emissions per capita CO_2 are measured in metric tons per capita and included since nuclear power is considered by some as a low carbon generation source although characterized by high lifecycle emissions [40].[8]

After explaining the construction of our polytomous dependent variable and describing our utilized categorical measure for the level of democratic development, Table 1 shows how the three different nuclear energy statuses descriptively relate to the three previously defined levels of democratic quality.

Our analysis covers 166 countries and 58 years which results in 9628 country-years. However, due to the unbalanced nature of our panel time series data set, a total number of 8266 observations is available for the combination of the level of democratic development and the nuclear energy status. The row frequencies thus represent how many observations for the respective level of democratic development fall into the respective category of nuclear energy status. Non-nuclear statuses dominate the sample. Within the given period, the majority of the total observations in our sample has been evaluated as democratically free. Within the non-nuclear group, more than 40% of the observations are either democratically free or not free. Democratically less free countries however clearly dominate the construction periods whereas "nuclear" statuses are characterized by higher percentages of democratically free countries. The nuclear statuses which follow the initial introduction of nuclear power not only occur more frequent in our sample but also correspond chronologically to the subsequent periods. It is thus not surprising that nuclear statuses are characterized by higher percentages of democratically free countries against the background of the tendency of overall increasing democracy levels of societies in the last several years and the transition to democracy of countries during the period 1985 and 1995 [44,45].

Table 2 reports the mean values and standard deviations for the explanatory variables in their respective nuclear status.

The continuous democracy variable $D1$ is the normalized democracy measure from Polity2 index running from 0 to 100 with greater values representing higher levels of democratic development [33]. *GDP* is GDP per capita and measured in constant 2010 USD. Urbanization *U* is measured as the share of the population living in urban areas. Electric power consumption *E* is measured in kWh per capita. Energy imports *EI* is measured in % of primary energy use. Fossil fuel rents *FFR* are the sum of oil rents, natural gas rents, coal rents and measured in

[6] We use the democracy indicator from the Polity IV Project instead of using data from Freedom House, another commonly used indicator for democratic quality, because the indicator from Freedom House is available only from 1972 on; 1989 data are missing; and Argentina, Armenia, Belgium, Brazil, Bulgaria, Canada, Finland, Germany, India, Italy, Japan, Kazakhstan, Korea, Rep., Netherlands, Pakistan, Slovak Republic, Spain, Sweden, Switzerland, and Ukraine all started constructing their first reactors before 1972. Put differently, if we use the indicator from Freedom House, we effectively loose information on 20 out of 38 (53%) countries which ever have build a nuclear power plant. A detailed description of the underlying methodology from the Polity IV Project is available at https://www.systemicpeace.org/. We moreover note that the various indicators for democracy such as the Freedom in the World rating from Freedom House, the Democracy Ranking by the Democracy Ranking Association, the Economist Intelligence Unit's Democracy Index, or the Democracy Barometer for instance vary in terms of their methodology and how democratic quality in particular is ranked and assessed. Democracy thus is a highly contested concept and measured in various ways as pointed out by two anonymous referees.

[7] The dates for nuclear warhead possession are based on Kristensen and Norris [37]. South Africa initially is not coded as a nuclear weapons states due to the lack of comparable information to Kristensen and Norris [37]. According to Jo and Garzke [38], the entire period of proliferation in South Africa dates from 1979 to 1991. Thus, we would have had to compare the period of a nuclear weapons program with the actual possession of at least one nuclear warhead. Our results, however, do not change if we code South Africa as a nuclear weapons state over the respective period. We thank an anonymous referee for raising this important issue.

[8] Evaluating 103 lifecycle studies of greenhouse gas-equivalent emissions for nuclear power plants, Sovacool [40] identifies the range of emissions for nuclear energy over the lifetime of a plant from 1.4 kg CO2-eq/MWh to 288 kg CO2-eq/MWh, with an average estimate of 66 kg CO2-eq/MWh. Lenzen [41] identifies the greenhouse gas intensities for light and heavy water reactors from 10 and 130 kg CO2-eq/MWh, with an average of 65 kg CO2-eq/MWh. The variability is due to different technologies and methodological differences between process chain analysis (PCA) and input-output analysis (IOA), the two main approaches used to assess emissions in a lifecycle analysis [42]. For an assessment of nuclear power regarding various sustainability development criteria, see Verbruggen et al. [43].

Table 1
Frequency table for the nuclear energy statuses at each level of democratic quality.

	Polity IV Project			
	F	*PF*	*NF*	Total
Non-nuclear	2833	1047	2966	6846
	(41.38)	(15.29)	(43.32)	(100)
Construction	50	28	96	174
	(28.74)	(16.09)	(55.17)	(100)
Nuclear	1111	26	109	1246
	(89.17)	(2.09)	(8.75)	(100)
Total	3994	1101	3171	8266
	(48.32)	(13.32)	(38.36)	(100)

Notes: *F*, *PF*, and *NF* correspond to democratically free, partly free, and not free for the measure of democratic quality *D*1 from Polity IV Project, respectively. Row percentages are in parentheses.

percentage of GDP. CO_2 emissions per capita CO_2 are measured in metric tons per capita.

Figs. 1–4 show the boxplots for all variables in three nuclear energy statuses.

The normalized democracy measure from the Polity2 index *D*1 is on average twice as high for the nuclear statuses compared to the construction statuses. *D*1 is 1.75 times higher for the nuclear statuses compared to the non-nuclear statuses. *D*1 is 1.18 times higher for the non-nuclear statuses compared to the construction statuses. Average GDP per capita is the largest for the nuclear statuses and the smallest for the construction statuses. Similarly, the range of GDP per capita is the largest for the nuclear statuses. Urbanization levels are highest for the nuclear and construction statuses compared to the non-nuclear statuses. Urbanization levels vary the most for the non-nuclear statuses compared to the nuclear and construction statuses. Average electric power consumption per capita is the highest for the nuclear statuses; they also show the most variability for electric power consumption. For the non-nuclear statuses, electric power consumption per capita is on average almost identical compared to the construction statuses. Nuclear statuses are characterized by positive values for the net energy imports indicator, whereas both non-nuclear and construction statuses are associated with negative values. Nuclear statuses on average tend to import energy, whereas non-nuclear and construction statuses are characterized by net energy exports. Construction statuses are characterized by the highest value for fossil fuel rents and also show the greatest variability for fossil fuel rents. Non-nuclear statuses have higher fossil fuel rents on average compared to nuclear statuses. Average CO_2 emissions per capita for the nuclear statuses are 1.43 (2.09) times higher compared to the construction (non-nuclear) statuses, whereas the average CO_2 emissions per capita for the construction statuses are 1.46 times higher compared to the non-nuclear statuses.

3.2. Methodological approach

Our categorical response variable contains more than two outcomes. The multinomial logistic regression approach thus is used to model relationships between a polytomous outcome variable and a set of predictor variables. The multinomial logit model builds on the binary logit model, but the factors which affect the outcomes are determined simultaneously which increases the efficiency of the estimates. The multinomial logistic regression approach uses the maximum likelihood estimation technique to establish the probability of group membership. The categories of the outcome variable are restricted to be unordered and based on the assumption of the independence of irrelevant alternatives (IIA) stating that the inclusion or exclusion of categories does not affect the relative risks associated with the remaining categories [46]. Hence, we utilize a multinomial logistic regression approach to analyze if a countries' choice to "go nuclear" is significantly influenced by the level of democratic development. In the multinomial logit model, the log-odds ratio that country i will fall in response category j relative to the reference category J is assumed to follow a linear model:

$$\eta_{ij} = \log\left(\frac{\pi_i^{(j)}}{\pi_i^{(J)}}\right) = \alpha^{(j)} + \beta_1^{(j)} X_{1i} + \ldots + \beta_k^{(j)} X_{ki}, \tag{1}$$

where π_i is the probability for outcome j in the $i = 1, \ldots, n$ countries, $\alpha^{(j)}$ is a constant, $\beta_1^{(j)}, \ldots, \beta_k^{(j)}$ are the k regression coefficients, for the $j = 1, \ldots, J-1$ outcomes, and $X_{1i}, \ldots, X_{ki}$ are the k explanatory variables.

We model a countries' nuclear energy strategy in which economies face the following j choices in the defined categorical dependent variable N: not using nuclear ($j = 0$, "non-nuclear"), constructing a nuclear power plant ($j = 1$, "construction"), and having at least one nuclear power plant fully operational ($j = 2$, "nuclear"). Since we specify "non-nuclear" as our reference category, we obtain a model for the log-odds of choosing "construction" over "non-nuclear":

$$\eta_{i1} = \log\left(\frac{\pi_i^{(1)}}{\pi_i^{(0)}}\right) = \alpha^{(1)} + \beta_1^{(1)} F_i + \beta_2^{(1)} PF_i + \beta_3^{(1)} NF_i + \beta_4^{(1)} W_i + \beta_5^{(1)} GDP_i + \beta_6^{(1)} U_i + \beta_7^{(1)} E_i + \beta_8^{(1)} EI_i + \beta_9^{(1)} FFR_i + \beta_{10}^{(1)} CO_{2i}, \tag{2}$$

and a second model for the log-odds of choosing "nuclear" over "non-nuclear":

$$\eta_{i2} = \log\left(\frac{\pi_i^{(2)}}{\pi_i^{(0)}}\right) = \alpha^{(2)} + \beta_1^{(2)} F_i + \beta_2^{(2)} PF_i + \beta_3^{(2)} NF_i + \beta_4^{(2)} W_i + \beta_5^{(2)} GDP_i + \beta_6^{(2)} U_i + \beta_7^{(2)} E_i + \beta_8^{(2)} EI_i + \beta_9^{(2)} FFR_i + \beta_{10}^{(2)} CO_{2i}, \tag{3}$$

where the factor variables F_i, PF_i, and NF_i correspond to the transformed normalized Polity2 index *D*1. We include a dummy variable indicator for nuclear warheads *W*, GDP per capita *GDP*, the share of urban population *U*, electric power consumption (kWh per capita) *E*, net energy imports (% of energy use) *EI*, fossil fuel rents (% of GDP) *FFR*, and CO_2 emissions (metric tons per capita) CO_2 A nomenclature is provided in Table 3.

Table 2
Arithmetic means and standard deviations of the seven explanatory variables for the three nuclear energy statuses.

	*D*1	*GDP*	*U*	*E*	*EI*	*FFR*	CO_2
Non-nuclear	49.76	8670.07	45.35	2330.84	-106.16	3.67	3.75
	(36.04)	(17834.67)	(24.51)	(3731.93)	(642.98)	(10.33)	(7.96)
Construction	42.24	8329.60	54.62	2372.46	-29.06	4.86	5.48
	(34.71)	(8670.71)	(16.63)	(2003.72)	(166.84)	(9.12)	(3.90)
Nuclear	87.19	20902.98	67.61	5451.87	37.52	1.15	7.84
	(24.02)	(16974.32)	(16.91)	(4056.77)	(37.68)	(2.66)	(4.76)

Notes: Arithmetic mean is shown and the standard deviation is in parentheses. Data on *D*1 are taken from the Polity IV Project. Data on *GDP, U, E, EI, FFR*, and CO_2 are taken from the World Development Indicators (WDI) database from The World Bank (last updated 24 April 2019).

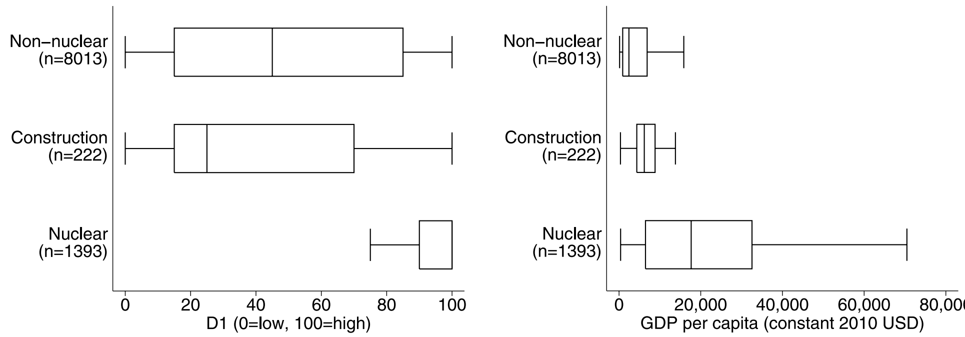

Fig. 1. Boxplots for *D*1 and *GDP* for the three nuclear energy statuses.

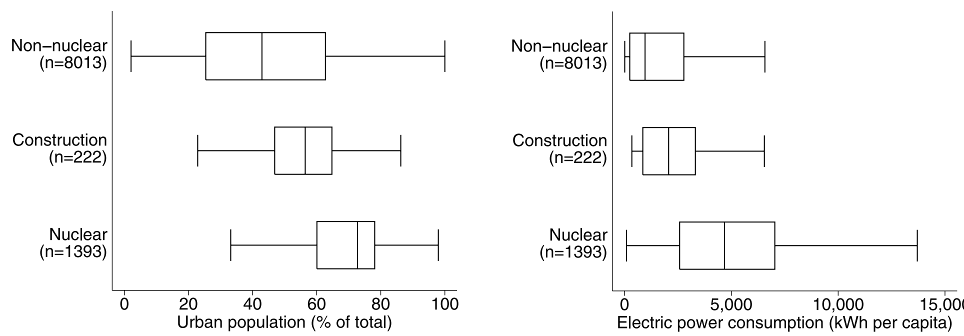

Fig. 2. Boxplots for *U* and *E* for the three nuclear energy statuses.

4. Empirical results

We start conducting model specification tests and test for the assumption of independence of irrelevant alternatives (IIA) of the multinomial logit model [47].[9] We first test if combining our dependent categories would increase the efficiency of our estimates. We thus test if a pair of outcomes is indistinguishable using both a Likelihood Ratio (LR) and Wald test. For both the LR and Wald test and for every pair of outcomes we can reject the null hypothesis that alternatives can be collapsed. This indicates that our models are efficiently defined in terms of the dependent categories. To assess if the effect of an independent variable equals zero across all equations we use both a LR and Wald test, to test the null hypothesis that all of the coefficients associated with an independent variable are simultaneously equal to zero across all equations. Again, for both the LR and Wald test, we can reject the null hypothesis that all coefficients for each regressor are equal to zero. Third, we test if the inclusion or exclusion of categories does not affect the relative risks associated with the remaining categories to evaluate if the outcome categories for the model have the property of IIA with the Hausman test of IIA [46]. The test statistics for all three categories are negative which suggests that the IIA has not been violated.[10]

We interpret the estimated parameters in Table 4 from the multinomial logistic regression approach relative to the reference group "non-nuclear". The results show the exponentiated estimates for the log-odds ratios associated with equations (2) and (3), respectively, which are interpreted in terms of the relative risk ratios (RRR). The RRR indicate how the probability of choosing alternative *j* relative to the reference group changes if the corresponding variable increases by one unit, ceteris paribus. We thus interpret the respective category of interest (partly free or not free) relative to the base category (free). In addition to our baseline estimations, we test if the results are driven by countries such as the United States or Russia which have nuclear weapons and nuclear power prior to the start of our study period.

All estimated parameters are statistically significant at least at the 10% level, except for the parameters on *PF, GDP*, and CO_2 in estimation (1), (2), and (3) for $j = 1$. The parameters on *FFR* are only statistically significant for $j = 1$ in estimation (1), (2), and (3). We begin interpreting the baseline estimation and the RRR for $j = 1$. The RRR for *NF* is above unity. Thus, for democratically not free countries compared to democratically free countries the relative risk of being in the construction group relative to the non-nuclear group would be expected to increase, ceteris paribus. Given all other variables held constant and compared to democratically free countries, the probability that democratically not free countries being in the construction group instead of in the non-nuclear group increases by 153% ($(2.526 - 1) \times 100$). In contrast, the RRR for the statistically not significant parameter on *PF* is below unity which indicates that for democratically partly free countries compared to democratically free countries the relative risk of being in the construction group relative to the non-nuclear group would be expected to decrease, ceteris paribus. The RRR for $j = 2$ for both *PF* and *NF* are below unity. Thus, for both democratically partly free and not free countries compared to democratically free countries the relative risk of being in the nuclear group relative to the non-nuclear group would be expected to decrease, ceteris paribus. Given all other variables held constant and compared to democratically free countries, the probability that democratically partly free countries are in the nuclear group instead of in the non-nuclear group decreases by 88%

[9] The results of all tests are available upon request. We inspect the correlations among variables to evaluate if multicollinearity affects our analyses. The results are in Table 10 in the appendix and indicate overall relatively low correlation among the variables. However, the correlation between *GDP* and *U, GDP* and *E, GDP* and CO_2, *U* and *E, U* and CO_2, and *E* and CO_2 exceeds 0.5.

[10] The Hausman test of IIA in general unfortunately provides rather inconsistent results thus providing little guidance whether the IIA assumption is violated or not. Based on simulations, Cheng and Long [48] show that the size properties of commonly used IIA tests depend on the data structure for the predictor variables. As a results, it is not uncommon that IIA tests often reject the assumption when the alternatives seem distinct and often fail to reject IIA when the alternatives can reasonably be viewed as close substitutes even in well-specified models [48]. They conclude that "[...] tests of the IIA assumption that are based on the estimation of a restricted choice set are unsatisfactory for applied work."

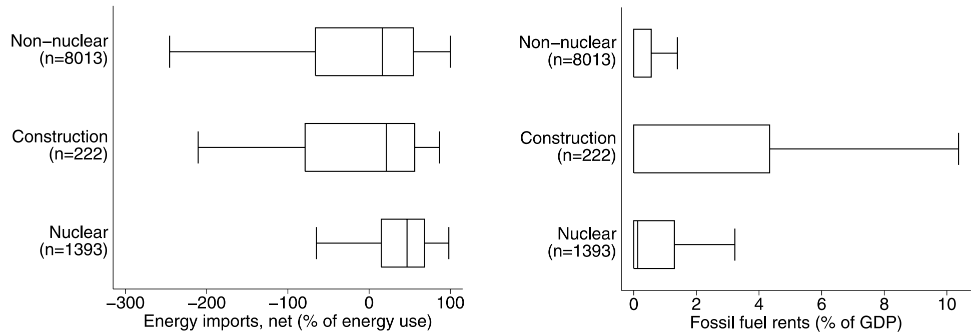

Fig. 3. Boxplots for *EI* and *FFR* for the three different nuclear energy statuses.

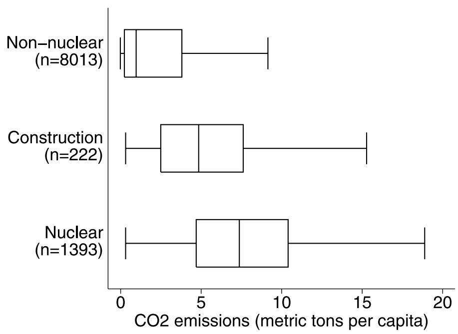

Fig. 4. Boxplots for CO_2 for the three nuclear energy statuses.

($(1 - 0.117) \times 100$). Similarly, given all other variables held constant and compared to democratically free countries, the probability of democratically not free countries being in the nuclear group instead of in the non-nuclear group decreases by 73% ($(1 - 0.275) \times 100$).

The RRR for W are above unity in both $j = 1$ and $j = 2$ yet differing substantially in magnitude. Thus for countries which possess at least one nuclear warhead compared to countries without a nuclear warhead, the relative risk of being in the construction group and nuclear group, respectively, relative to the non-nuclear group would be expected to increase, ceteris paribus. Given all other variables held constant and compared to countries without a nuclear warhead, the probability that countries which possess at least one nuclear warhead are in the construction group instead of in the non-nuclear increases by 342% ($(4.424 - 1) \times 100$). Similarly, given all other variables held constant and compared to countries without a nuclear warhead, the probability that countries which possess at least one nuclear warhead are in the

Table 3
Nomenclature.

List of used acronyms			
IIA	Independence of Irrelevant Alternatives	PRIS	Power Reactor Information System
GLMM	Generalized Linear Mixed Model	PSI	Political Stability Index
IAEA	International Atomic Energy Agency	PITF	Political Instability Task Force
LR	Likelihood Ratio	RRR	Relative Risk Ratio
MLP	Multi-Level Perspective	WNA	World Nuclear Association
NPT	Nuclear Non-Proliferation Treaty	WDI	World Development Indicators
List of used variables			
D_1	Continuous democracy indicator	U	Urbanization,
F	Democratically free	E	Electric power consumption per capita
PF	Democratically partly free	EI	Energy imports
NF	Democratically not free	FFR	Fossil fuel rents
W	Nuclear warhead possession	CO_2	CO_2 emissions per capita
GDP	GDP per capita		

Table 4
Estimations (1) to (3) with categorized democratic quality from Polity IV Project.

	(1) Baseline		(2) Baseline no USA		(3) Baseline no Russia	
	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)
PF	0.842	0.117^a	0.841	0.118^a	0.865	0.0859^a
NF	2.526^a	0.275^a	2.523^a	0.280^a	2.521^a	0.291^a
W	4.424^a	20.56^a	4.333^a	18.22^a	4.452^a	16.68^a
GDP	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a
U	1.028^a	1.023^a	1.028^a	1.023^a	1.029^a	1.022^a
E	1.000^b	1.000^a	1.000^b	1.000^a	1.000^c	1.000^a
EI	1.002^a	1.008^a	1.002^a	1.008^a	1.002^a	1.008^a
FFR	1.029^a	0.983	1.029^a	0.985	1.029^a	0.974
CO_2	1.045	0.963^a	1.045	0.959^a	1.045	0.962^a
$cons$	0.00450^a	0.0544^a	0.00451^a	0.0547^a	0.00445^a	0.0571^a
N	4844		4789		4821	
Pseudo R^2	0.279		0.259		0.274	

Notes: RRR is shown. Superscripts *a, b,* and *c* represent significance at 1%, 5%, and 10%, respectively. Democratically free F is the base category. The reference group is non-nuclear ($j = 0$).

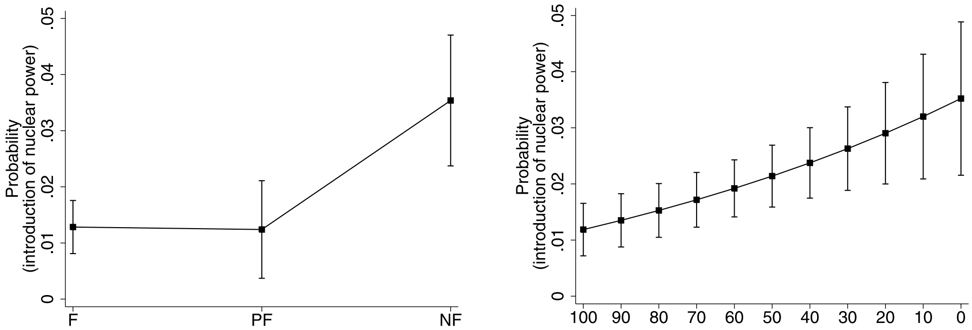

Fig. 5. Adjusted predictions with 95% confidence interval for group membership of introduction of nuclear power by level of democratic quality **Notes:** Left plot indicates categorized levels and right plot indicates continuous levels based on the Polity IV Project democracy measure. *F, PF*, and *NF* are democratically free, partly free, and not free, respectively. Continuous levels of democratic quality on the horizontal axis in the right plot correspond to *D*1. Higher values represent higher levels of democratic development [33].

nuclear group instead of in the non-nuclear increases by 1956% ($(20.56 - 1) \times 100$).

The RRR for *U* and *EI* are above unity for $j = 1$ as well as for $j = 2$. Thus, a one unit increase in *U* or *EI* increases the probability that to "go nuclear" (to be nuclear) is chosen instead of non-nuclear (non-nuclear). Countries which become rather energy importers are more likely to both construct and continue to use nuclear power. The RRR for *FFR* is above unity for $j = 1$. Thus, a one unit increase in *FFR* increases the probability that to "go nuclear" is chosen instead of non-nuclear. Increases in fossil fuel rents, which effectively function as an asset like any other stock of capital, increase the probability of entering construction. The RRR for CO_2 is below unity for $j = 2$. Thus, a one unit increase in CO_2 decreases the probability that to be nuclear is chosen instead of non-nuclear. The result indicates that choosing to continue using nuclear power historically is not mainly motivated by CO_2 emission reduction efforts to tackle climate change. The abatement of greenhouse gas emissions moreover has been identified only recently as a potential factor emerging in the environmental policy realm [10]. Considering the national development and both energy transitions and environmental indicators only, the impact of a one unit increase on the probability that to "go nuclear" and to be nuclear is chosen instead of non-nuclear is the greatest in magnitude for *U*. If two countries are identical except for their urbanization levels, the country with higher urbanization is more likely to choose to "go nuclear" and to be nuclear than the country with lower urbanization. The RRR for both *GDP* and *E* are equal to one for $j = 1$ as well as for $j = 2$ which indicates a rather unsubstantial effect of both variables for defining the nuclear energy strategy chosen over time. Considering the magnitude of all of the estimated parameters, both democracy and possession of a nuclear warhead tend to have the largest impact on the nuclear energy strategy chosen over time. Overall, the results do not vary substantially when we exclude the United States or Russia.

Fig. 5 shows the predicted probabilities from our baseline estimation for democratic quality while holding all other variables at their means. The left plot illustrates the predicted probabilities for the introduction of nuclear power at each level of democratic freedom - free *F*, partly free *PF*, not free *NF* - while holding all other variables at their means.

The predicted probability for introducing nuclear power increases with decreasing levels of democratic freedom. While the predicted probability for the introduction of nuclear power is slightly higher for democratically free countries than for democratically partly free countries considering the point estimates, the upper bound of the confidence interval for democratically partly free countries is considerably greater in magnitude compared to democratically free countries. The right plot indicates the predicted probabilities for continuous levels of democratic quality while holding all other variables at their means. Greater values represent higher levels of democratic development. The predicted probability for introducing nuclear power increases with decreasing levels of democratic freedom. Generally, democracy effects and the possession of a nuclear warhead tend to dominate a countries' nuclear energy strategy chosen over time instead of national development and both energy transitions and environmental indicators with the exception of urbanization levels.

5. Robustness

We conduct several robustness checks. First, we create a dummy for the transitional years covering the period 1989 to 1992 to capture year effects which affect all countries between the fall of the Berlin Wall and the collapse of the Soviet Union. We also use a specification with year effects to capture the influence of aggregate time-series trends. Second,

Table 5
Estimations (4) and (5) with categorized democratic quality from Polity IV Project with transitional period dummy and year effects.

	(4) Dummy		(5) Year Effects	
	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)
PF	0.843	0.117^a	1.076	0.113^a
NF	2.526^a	0.275^a	1.979^b	0.253^a
W	4.438^a	20.59^a	4.299^a	21.59^a
GDP	1.000	1.000^a	1.000^b	1.000^a
U	1.029^a	1.023^a	1.031^a	1.024^a
E	1.000^b	1.000^a	1.000	1.000^a
EI	1.002^a	1.008^a	1.003^a	1.008^a
FFR	1.030^a	0.983	1.073^a	0.995
CO_2	1.045	0.963^a	0.979	0.952^a
Dummy 1989 - 1992	1.148	1.051	-	-
Year Effects	no	no	yes	yes
cons	0.00443^a	0.0541^a	0.0950^a	0.0318^a
N	4844		4844	
Pseudo R^2	0.279		0.302	

Notes: RRR is shown. Superscripts *a, b*, and *c* represent significance at 1%, 5%, and 10%, respectively. Democratically free *F* is the base category. The reference group is non-nuclear ($j = 0$).

Table 6
Estimations (6) to (12) with categorized democratic quality from Polity IV Project.

	(6)		(7)		(8)		(9)	
	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)
PF	1.515^c	0.0633^a	1.539^c	0.0719^a	1.359	0.101^a	1.502	0.113^a
NF	1.834^a	0.0937^a	1.833^a	0.0933^a	2.102^a	0.126^a	2.557^a	0.172^a
W			3.372^a	23.42^a	3.660^a	21.80^a	4.187^a	22.48^a
GDP					1.000	1.000^a	1.000^a	1.000
U							1.031^a	1.033^a
cons	0.0176^a	0.392^a	0.0172^a	0.312^a	0.0142^a	0.228^a	0.00340^a	0.0400^a
N	8266		8266		7055		7045	
Pseudo R^2	0.128		0.192		0.203		0.238	
	(10)		(11)		(12)		(1)	
	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)
PF	0.942	0.110^a	0.994	0.120^a	0.874	0.122^a	0.842	0.117^a
NF	2.603^a	0.154^a	3.008^a	0.258^a	2.615^a	0.269^a	2.526^a	0.275^a
W	4.583^a	20.80^a	4.370^a	19.01^a	4.512^a	19.44^a	4.424^a	20.56^a
GDP	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a
U	1.030^a	1.025^a	1.030^a	1.021^a	1.029^a	1.021^a	1.028^a	1.023^a
E	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a	1.000^b	1.000^a
EI			1.001	1.008^a	1.002^a	1.007^a	1.002^a	1.008^a
FFR					1.032^a	0.973^c	1.029^a	0.983
CO_2							1.045	0.963^a
cons	0.00431^a	0.0663^a	0.00410^a	0.0565^a	0.00430^a	0.0587^a	0.00450^a	0.0544^a
N	4866		4860		4860		4821	
Pseudo R^2	0.234		0.274		0.276		0.274	

Notes: RRR is shown. Superscripts *a*, *b*, and *c* represent significance at 1%, 5%, and 10%, respectively. Democratically free *F* is the base category. The reference group is non-nuclear (j = 0).

we gradually increase a parsimonious specification which only includes the democracy control factor variable with the other relevant predictors until we arrive at the baseline specification given in equations (2) and (3), respectively. Third, we redo the entire analysis but use the democracy measure from the normalized Polity2 index in continuous modes. Table 5 presents the results with an additional dummy covering the period 1989 to 1992 as well as with year effects included.

The results are identical to our baseline estimation in significance and magnitude for all of the estimated parameters in both j = 1 and j = 2. The time dummy for 1989 to 1992 is statistically not significant for either j = 1 or j = 2, which indicates that the effects of the transitional period into the post-cold war era do not significantly impact the nuclear energy strategy chosen over time. If we capture the influence of aggregate time-series trends with year effects, significance and magnitude do not change. We can reject the null hypothesis that the coefficients for all years are jointly equal to zero at the 10% level significance level. The main implications remain the same. For democratically not free countries compared to democratically free countries the relative risk of being in the construction group relative to the non-nuclear group would be expected to increase, ceteris paribus. Similarly, countries which possess at least one nuclear warhead compared to countries without a nuclear warhead, are more likely to be in the construction group and nuclear group, respectively, relative to the non-nuclear group.

Table 6 shows the results of our second robustness check which do not alter the main implications.

When we gradually increase a parsimonious specification which only includes the democracy control factor variable with the other relevant predictors, the results still suggest that i) in particular for democratically not free countries compared to democratically free countries the relative risk of being in the construction group relative to the non-nuclear group would be expected to increase and ii) that for both democratically partly free and not free countries compared to democratically free countries the relative risk of being in the nuclear group relative to the non-nuclear group would be expected to decrease. Moreover, similar to our baseline estimation, the RRR for *W* for both j = 1 and j = 2 is always above unity which indicates that countries which possess at least one nuclear warhead compared to countries without, the relative risk of being in the construction and nuclear group, respectively, relative to the non-nuclear group would be

Table 7
Estimations (13) to (15) with continuous democratic quality from Polity IV Project

	(13) Baseline		(14) Baseline no USA		(15) Baseline no Russia	
	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)	Construction (j = 1)	Nuclear (j = 2)
*D*1	0.991^a	1.024^a	0.991^a	1.023^a	0.991^a	1.023^a
W	4.614^a	21.89^a	4.525^a	19.57^a	4.756^a	19.07^a
GDP	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a
U	1.027^a	1.021^a	1.027^a	1.021^a	1.027^a	1.021^a
E	1.000^c	1.000^a	1.000^c	1.000^a	1.000^c	1.000^a
EI	1.002^a	1.007^a	1.002^a	1.008^a	1.002^a	1.007^a
FFR	1.030^a	0.995	1.030^a	0.997	1.030^a	0.987
CO_2	1.044	0.962^a	1.045	0.959^a	1.044	0.962^a
cons	0.0118^a	0.00727^a	0.0118^a	0.00748^a	0.0116^a	0.00780^a
N	4844		4789		4821	
Pseudo R^2	0.279		0.259		0.273	

Notes: RRR is shown. Superscripts *a*, *b*, and *c* represent significance at 1%, 5%, and 10%, respectively. *D*1 is the continuous democracy measure. The reference group is non-nuclear (j = 0).

Table 8
Estimations (16) and (17) with continuous democratic quality from Polity IV Project with transitional period dummy and year effects.

	(16) Dummy		(17) Year Effects	
	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)
$D1$	0.991^a	1.024^a	0.995^c	1.024^a
W	4.627^a	21.92^a	4.490^a	22.99^a
GDP	1.000	1.000^a	1.000^b	1.000^a
U	1.027^a	1.021^a	1.030^a	1.022^a
E	1.000^c	1.000^a	1.000	1.000^a
EI	1.002^a	1.008^a	1.003^a	1.008^a
FFR	1.030^a	0.995	1.076^a	1.006
CO_2	1.044	0.962^a	0.977	0.952^a
Dummy 1989 - 1992	1.160	1.060	-	-
Year Effects	no	no	yes	yes
cons	0.0116^a	0.00722^a	0.179^a	0.00375^a
N	4844		4844	
Pseudo R^2	0.280		0.304	

Notes: RRR is shown. Superscripts *a, b*, and *c* represent significance at 1%, 5%, and 10%, respectively. $D1$ is the continuous democracy measure. The reference group is non-nuclear ($j = 0$).

expected to increase.

The results for our last robustness check in which we redo the entire analysis utilizing democratic quality in continuous modes, are presented in Tables 7–9. If we redo the entire analysis but use the democracy measures from the Polity IV Project in continuous modes, the results indicate that if a country increases its democracy level, we would expect this country to be more likely to choose non-nuclear over going nuclear which supports our main findings.

Based on our empirical analysis, the overall results indicate the following: We robustly find i) that in particular for democratically not free countries compared to democratically free countries the probability of being in the construction group relative to the non-nuclear group would be expected to increase whereas this probability decreases for the nuclear group and robustly for all estimations ii) that countries which possess at least one nuclear warhead compared to countries without are more likely to choose to construct a nuclear power plant and to use nuclear power, respectively, instead of not using nuclear power at all. Overall, the estimated probability for being a democratically not free country in the construction group instead of in the non-nuclear group ranges from 83% to 200%. The estimated probabilities for construction and the continued use of nuclear for countries possessing at least one nuclear warhead compared to countries that do not have a nuclear warhead ranges from 228% to 384% in the case of construction and from 1568% to 2635% in the case of the continued use of nuclear. Again, possession of a nuclear warhead tends to encourage the continued use of nuclear energy.

Our results regarding the democratic realm are broadly supported by Yamamura [31] for freedom of expression and free media which significantly influences views on the security of nuclear power plants: Citizens tend to disagree that nuclear power plants are properly secured against accidents when the political setting assures both freedom of expression and media to a greater extent. In terms of nuclear weapons, our results contrast Fuhrmann [13] who finds the impact of nuclear weapons exploration on the likelihood for construction to be statistically not significant.

6. Conclusion

This paper analyzes how a countries' choice to introduce nuclear power is influenced by the level of democratic development. Our

Table 9
Estimations (18) to (24) with continuous democratic quality from Polity IV Project.

	(18)		(19)		(20)		(21)	
	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)
$D1$	0.994^a	1.041^a	0.994^a	1.041^a	0.993^a	1.036^a	0.990^a	1.030^a
W			3.281^a	27.35^a	3.688^a	25.44^a	4.334^a	24.68^a
GDP					1.000	1.000^a	1.000^a	1.000
U							1.030^a	1.031^a
cons	0.0332^a	0.0103^a	0.0323^a	0.00811^a	0.0301^a	0.0101^a	0.00935^a	0.00317^a
N	8266		8266		7055		7045	
Pseudo R^2	0.151		0.216		0.218		0.247	
	(22)		(23)		(24)		(13)	
	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)	Construction ($j = 1$)	Nuclear ($j = 2$)
$D1$	0.990^a	1.029^a	0.988^a	1.024^a	0.990^a	1.024^a	0.991^a	1.024^a
W	4.835^a	22.30^a	4.601^a	20.50^a	4.702^a	20.78^a	4.614^a	21.89^a
GDP	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a
U	1.029^a	1.024^a	1.029^a	1.019^a	1.027^a	1.019^a	1.027^a	1.021^a
E	1.000	1.000^a	1.000	1.000^a	1.000	1.000^a	1.000^c	1.000^a
EI			1.001	1.007^a	1.002^a	1.007^a	1.002^a	1.007^a
FFR					1.032^a	0.984	1.030^a	0.995
CO_2							1.044	0.962^a
cons	0.0118^a	0.00506^a	0.0132^a	0.00737^a	0.0117^a	0.00777^a	0.0118^a	0.00727^a
N	4866		4860		4860		4844	
Pseudo R^2	0.241		0.275		0.277		0.279	

Notes: RRR is shown. Superscripts *a, b*, and *c* represent significance at 1%, 5%, and 10%, respectively. $D1$ is the continuous democracy measure. The reference group is non-nuclear ($j = 0$).

empirical analysis is based on a panel time series data set with 166 countries covering the period 1960 to 2017. We utilize a multinomial logistic regression approach to evaluate how different stages of a countries' nuclear energy strategy - not using nuclear power at all, construction, and continued use of nuclear power - relates to different levels of democratic development. Our empirical results robustly show that historically, democratically not free countries compared to democratically free countries are more likely to introduce nuclear power instead of not using nuclear power at all. Moreover, countries possessing at least one nuclear warhead compared to countries without a nuclear warhead are more likely to decide to use nuclear power. Democracy effects and possession of a nuclear warhead have a significant effect on the nuclear energy strategy chosen over time.

The introduction of nuclear energy thus tends to be more likely under conditions where political and public debate are minimized which more easily enables the implementation of governmental programs which might run contrary to public interest. Decisions regarding nuclear power are moreover influenced by private and/or governmental technocracy which can overpower democratic steering and control processes detrimentally. When technocracy can influence its regulators, it can also impact deliberative forums and public engagement to foster incumbent nuclear policy which is in contrast to the encouragement of sustainable development policy. Government policy however can address these issues by a more pronounced public involvement in decisions regarding nuclear power and by increasing stakeholder involvement at all aspects of the nuclear fuel cycle including uranium mining, radioactive waste management, location of new nuclear power plants, emergency situations and rehabilitation of contaminated territories [43].

The political setting moreover tends to dominate and overpower both the social and economic dimension at least in less democratic environments when it comes to nuclear energy deployment. Certainly, nuclear power requires a specific type of governance due to the very specific safety requirements of nuclear power plants and their impact on society. The very specific conditions in large-scale energy infrastructure projects such as institutional exceptions then tend to have an impact on the practices and institutions which define the governance of a project [49]. We thus provide empirical evidence on how certain political environments favor the implementation of large-scale energy infrastructures with lifespans over decades. It becomes more difficult for countries to move towards decentralized energy technologies that are considered to more readily organize and enable distributed political and economic power which effectively can create a technological lock-in, if the nuclear electricity industry moreover is both highly concentrated and connected with related policy decisions [50]. How to overcome a potential nuclear lock-in partly induced due to certain political environments is a conversely related question which also derives from our empirical analysis. Aspects of democratic quality similarly impact the nuclear energy strategy for either continuity or disruption of nuclear power. In particular against the background of the democratic deficits associated with nuclear power, qualities of democracy appear to be an inconspicuous yet highly relevant factor connected also to nuclear discontinuity. Finland can be seen as an exception as nuclear new builds are planned in this country [20].

Due to the dual-use dilemma nuclear energy faces, our analyses moreover have implications beyond energy and environmental policy addressing international relations, conflict, and security issues. Nuclear weapon aspirations or possession thereof might be accompanied by the pursuit of nuclear power, and vice versa. The ownership of nuclear weapons then can eventually impede a nuclear phase out globally. But similarly, the desire for nuclear warheads can motivate countries to construct nuclear power plants. In countries such as China, India, and Pakistan, the introduction of nuclear power for civil purposes was only possible in conjunction with developing nuclear weapons through mobilizing extraordinary political will and resources [29]. The synergies between military use of nuclear power and electricity generation in countries such as Iran could result in a multi-nuclear Middle East with both Saudi Arabia and Egypt most likely being candidates choosing to "go nuclear" very soon in a response to a potential Iranian warhead [51].

We suggest that future research should emphasize additional geopolitical and military aspects of nuclear power deployment. Specific aspects of qualities of democracy and their impacts on different nuclear trajectories also need to be analyzed. For example, are countries within proximity of hostile countries with nuclear intercontinental ballistic missiles more likely to construct nuclear power plants? Does country membership in a defense alliance affect its nuclear power deployment? Connecting the different dimensions of democratic quality with the utilization of nuclear energy is expected to provide further insights into the current and future development of nuclear power. Building upon the work from Johnstone and Stirling [20], it would be of particular interest to investigate how different aspects of democratic quality impact the decision to phase out nuclear power. In this regard, we suggest considering the potential effects of specific democratic elements such as the rule of law, participation, competition, both vertical and horizontal accountability, respect for civil and political freedoms, progressive implementation of greater political equality, and responsiveness on which democracies diverge in terms of quality to evaluate which democratic characteristics are the most important to explain the difference in nuclear energy trajectories among countries.

Declaration of Competing Interest

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.

Appendix A

Table 10
Correlation matrix.

Variables	*N*	*D*1	*W*	*GDP*	*U*	*E*	*EI*	*FFR*	CO_2
N	1.000 *D*1	0.351^a	1.000						
W	0.364^a	0.124^a	1.000						
GDP	0.243^a	0.314^a	0.116^a	1.000					
U	0.320^a	0.352^a	0.139^a	0.596^a	1.000				
E	0.313^a	0.280^a	0.122^a	0.812^a	0.583^a	1.000			
EI	0.104^a	0.213^a	0.042^a	-0.055^a	-0.024^c	0.011	1.000		
FFR	-0.087^a	-0.246^a	-0.027^a	0.060^a	0.187^a	0.068^a	-0.441^a	1.000	
CO_2	0.188^a	0.094^a	0.114^a	0.722^a	0.546^a	0.629^a	-0.196^a	0.312^a	1.000

Notes: Superscripts *a*, *b*, and *c* represent significance at 1%, 5%, and 10%, respectively.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.erss.2019.101389

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