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Original Article

Examination of different socioeconomic factors that contribute to the public acceptance of nuclear energy

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ABSTRACT

Public acceptance is a major issue that will determine the future of nuclear energy. In this article, we review relevant studies and identify several common patterns of nuclear public acceptance. Based on these patterns and four categories of factors, we propose hypotheses on the impact of different socio-economic factors on the public opinion of nuclear energy. These factors were demographic and social influences, politico-economic, energy conditions, and nuclear accidents and natural risks. We tested these hypotheses using a data set including survey results on public opinion of nuclear energy in 59 countries from 1987 to 2014. Results of the regression analysis generally verified the proposed hypotheses, especially regarding the positive impact of education or geological suitability and the negative effect of improved living standards and democracy on nuclear acceptance. We propose policy recommendations, including a better focus on education and communication and a thorough consideration of the social and geological conditions a country needs to make before deciding to go nuclear. Potential weaknesses of this study are also discussed, including the possible causal relation between independent variables and the binary nature of the dependent variable.

1. Introduction

The success or failure of a civil nuclear power program strongly depends on the acceptance of nuclear technology by the public. Even before the nuclear accidents at Three Mile Island and Chernobyl, public perception was already identified to be the most critical factor affecting the future of nuclear power [1,2]. Arising from such a need to study and enhance the public acceptance of nuclear energy, characterization of nuclear risk perception was initiated in the 1970s through numerous psychometric studies. These studies found that the American public considered nuclear power the riskiest technology in terms of both consequence and uncontrollability [3]. However, more recent studies in the United States (US) showed that the difference in the level of negative opinion between nuclear and other types of electricity generation like coal or wind has been largely reduced, especially taking into account the environmental advantages of each type [4]. To explain such a changing attitude toward nuclear energy, structural understanding of nuclear perception has been proposed, in which perceived risk, perceived benefit, and trust in institutions have often been found to be major components [5]. It is essential to recognize the interdependence between, and the different weighting factors of, such components. In this article, we present a review of the literature on the formation of the public perception or acceptance of nuclear energy. This qualitative discussion is followed by a quantitative analysis of identifying key factors affecting public acceptance of nuclear energy (also called public nuclear acceptance) as part of the effort to examine public nuclear acceptance patterns in different countries.

2. Literature review

2.1. Demographic, social, and politico-economic aspects of public acceptance

There is a consensus that women tend to have higher perceived risk attitude against technology such as nuclear technology. Such high risk perception may come from a gender-based biological factor like maternity or from a relatively lower familiarity with technology than men have due to the lower percentage of women who study engineering subjects [6]. From this observation, we can assume that gender is a major factor in the formation of public

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nuclear acceptance. Researchers have also identified age as another factor in explaining public nuclear acceptance, with the younger population showing more support for new nuclear plants than the older generation [7]. Regarding the role of education, people unfamiliar with science and technology tend to have more risk-averse attitudes, whereas people with a sufficient level of knowledge were found to have more favorable opinion about nuclear energy [8]. Similarly, scientists were found to have far lower perceived risk of nuclear energy than laypeople [9]. Consequently, numerous studies have argued that education plays an important role in increasing public understanding of nuclear energy [10]. Others, while agreeing on the positive impact of education, noted that the contribution from education is strongly affected by other factors like personal beliefs or preexisting convictions of people with such education [11].

The robustness of a country's democracy, which can be reflected through the freedom of expression and of the press, has been considered a major factor influencing the public perception of nuclear energy [12]. For example, it was found that the media has contributed to the increasingly negative public perception of nuclear risk, as nuclear-related subjects often contain powerful messages about nuclear dangers, painting a gloomy picture about nuclear power while ignoring the benefits of nuclear power in the mitigation of global climate change [13]. This negative depiction of nuclear energy by the media has been further aggravated by a lack of trust by the public in the authority along with activities of special interest groups, even in the presence of scientific information about the safety of the technology [14]. On the other hand, the prevalence of technocrat culture in countries like France, China, or India, where scientists are well respected, was identified to be a major reason behind the relatively positive attitude of the public toward nuclear energy [15]. Finally, economic conditions also affect the public perception of nuclear energy, as people with better living standard tend to disfavor nuclear energy [16].

2.2. Energy-related, natural, and other technological risk factors

Energy security has been considered a major contributor to the public support and government policy for nuclear energy development [17]. In the Republic of Korea, for example, the public concern of underdevelopment caused by the lack of energy was thought to be the reason for the support for the Republic of Korea nuclear program [18]. Furthermore, it was argued that people in countries with established nuclear programs tend to be well informed about nuclear benefits and risks and thus have favorable views about the technology [19]. Similarly, as proximity to nuclear facilities often leads to familiarity with the technology and direct benefits, nuclear energy often enjoys stronger support from the local communities near the plant sites [20]. As the fluctuation of oil price has a major impact on energy security, it can also indirectly influence the public perception of nuclear power development [21]. The availability of renewable resources is another factor that can potentially lower the support for nuclear energy [22]. Recently, the positive impact of nuclear energy on climate change, thanks to its negligible emissions, has become a new push for acceptance of this technology, even among former antinuclear activists [13].

As discussed in the introduction, perceived risk of nuclear power was found to be exceptionally high among the public in comparison with other types of technologies. In addition, numerous studies have shown that the nuclear accidents at Three Mile Island (1979), Chernobyl (1986), or Fukushima (2011) have significantly damaged the public acceptance of nuclear power [14,23]. However, results of longitudinal surveys conducted before and after the accidents showed that public opinion of nuclear energy was only temporarily affected by these events before returning to the preaccident trend within a year or two [24]. Furthermore, it was noted that such stabilization was more remarkable in established nuclear countries, as the public was able to identify positive features of nuclear energy to compensate for its negative image brought by the accidents [14]. Geological conditions can also affect the public opinion on the development of nuclear-related facilities, such as plant sites, final disposal sites, and reprocessing plants. For example, the seismic stability of the available bedrock in Sweden and Finland has helped maintain the public support for the construction of geological disposal repositories; whereas, the negative public opinion in Japan about spent fuel management has been partly attributed to the unstable geology of this country [25].

3. Methodology and data

3.1. Research hypotheses

One observation made from the literature review is that public acceptance of nuclear energy may vary year to year and also differ geographically from one country to another. Such variation exists because the public support for this technology is heavily conditioned by the distinctive sociological and cultural characteristics of, or related events occurring in, each country. However, similar patterns of nuclear acceptance have been found in country-specific studies done in different periods [26]. Accordingly, based on the above qualitative discussion, we propose four hypotheses about universal patterns of nuclear public acceptance:

Hypothesis 1. Essential demographic and social characteristics, such as the proportion of females in the population, the level of public education, and the prevalence of working-age population, have a correlation with nuclear public acceptance across countries and periods.

Hypothesis 2. There is also a correlation between nuclear public acceptance and the politico-economic conditions of a country, such as the level of democracy or the living standards.

Hypothesis 3. Energy security, including oil prices and the availability of alternative energy sources, and the existence of a nuclear power program have a universal impact on public acceptance of nuclear energy.

Hypothesis 4. Countries' exposure to natural disasters, seismic concerns, and the occurrence of nuclear accidents negatively affect the public acceptance of nuclear energy, although such impact is short-lived.

3.2. Nuclear acceptance data set

To examine these hypotheses, we needed to develop a data set for public acceptance of nuclear energy that covers multiple states through consecutive years. However, such data gathering is difficult because of the lack of longitudinal studies that reflect the changing perceptions of nuclear energy by the public through time. In addition, because of the complex and costly nature of surveys, studies of this type are available only in a limited number of countries. With an understanding of these limitations, we developed a data set of nuclear public acceptance worldwide by collecting survey data from academic papers and reports by agencies specialized in opinion polls. Covering 1987–2014, the data includes nationwide public opinion of nuclear energy from 59 countries, including all 28 states with operating nuclear power plants (NPPs), four former nuclear states, 16 aspiring states planning their first NPP, and another 11 countries with relevant data. It is important to note that, despite the obvious differences between countries with

and without NPPs, data from both categories were included for the examination of the impact of the existence of operating NPPs on nuclear acceptance.

3.3. Dependent and independent variables

To represent the level of nuclear public acceptance in a specific country i in a certain year j, the dependent variable that is the net support percentage of nuclear energy ($support\_net_{i,j}$) was defined as follows:

$$support\_net_{i,j} = support\_percentage_{i,j} - oppose\_percentage_{i,j} \quad (1)$$

where $support\_percentage_{i,j}$ is the fraction of respondents supporting nuclear energy, and $oppose\_percentage_{i,j}$ is the fraction of respondents against nuclear energy. Therefore, the net support percentage of nuclear energy ranges between 1 and −1 (i.e., $-1 \leq support\_net_{i,j} \leq 1$).

There have been arguments against the use of a straightforward question like "Do you support the use of nuclear energy?" for public survey due to its simplicity [19]. Nevertheless, it has been widely used to represent the level of nuclear public acceptance, as more sophisticated framing of the question may inadvertently affect the survey outcome [27]. Thus, we only collected the results coming from this question and its close variations. Based on a linear model of risk perception, according to which the perceived collective risk from traditional technologies is assumed to be linearly correlated with risk aversion factors and the magnitude of consequence, we examined the hypotheses proposed in this study using Formula (2) [12]:

$$\Pr(nuclear\ support) = support\_net_{i,j} = \beta_0 + \sum_{k=1}^{n} \beta_k \times independent\ variable_{i,j,k} \quad (2)$$

with n being the number of independent variables considered for this model.

For the independent variables, the socioeconomic data of the included countries from 1987 to 2014 were collected and are described in Table 1. The collinearity among the variables was checked through the calculation of their variance inflation factors. The results showed low variance inflation factors across variables, which indicated the nonexistence of statistical distortion caused by the multicollinearity effect [28]. In particular, to estimate the psychological impacts of nuclear accidents, an exponential Formula (3) was proposed by taking into account the following findings: (i) nuclear accidents do impact public acceptance negatively but mostly in the short term; (ii) negative psychological consequences of nuclear accidents are more apparent in states where the accident occurred [29]; and (iii) the bigger the accident, the stronger the impact.

$$Impact(t,d) = e^{-t/m} \times e^{-d/m} \quad (3)$$

with t being the time since the accident (in year), d being the distance from the accident's country of origin, and m being the International Nuclear Events Scale of the event.

4. Results and discussions

4.1. Results of the quantitative analysis

The statistical significances of the correlation between dependent and independent variables using linear and multinomial logistic regression analyses are presented in Table 1. Results show that there is a significant correlation between nuclear public acceptance and most of the independent variables. Such correlation, however, was not found in the case of *press_score* (freedom of press) or in the case of the psychological impact of the three nuclear accidents (*tmi_impact, chenobyl_impact, and fukushima_impact*). To determine the statistical impact of the independent variables on public nuclear acceptance according to the model presented in Formula (2), we calculated the percentage change in the model result when the value of the variable in consideration was increased from 0 to 1 (for dichotomous variables) and from its mean to one standard deviation above the mean (for continuous variables), while keeping all others at their means [30]. The results of this calculation are shown in Fig. 1.

Table 1
Results of the linear and multinomial logistic regression analysis of the nuclear acceptance database with the statistical significance (*sign*) of correlations between dependent and independent variables.

Independent variable	Description	Linear regression			Multinomial logistic regression		
		Estimate	*Pr(>|t|)*	*Sign*	*Chisq*	*Pr(>Chisq)*	*Sign*
Demographic and social factors							
Female_pc	Female proportion in total population	*−0.62386*	*0.00191*	**	9.1502	0.027359	*
demo_15_64	Percentage of working-age people (15–64)	*0.284963*	*0.09648*		8.5767	0.035482	*
edu_attain	Average years of continuous education per resident	*0.672981*	*3.16E-10*	***	9.2996	0.025561	*
Politico-economic factors							
log_gdppc	Logarithmic value of GDP per capita	*−0.99692*	*2E-16*	***	8.2735	0.040685	*
polity	Democracy Polity IV score	*−0.12855*	*0.01528*	*	11.9845	0.007437	**
press_score	Freedom of the press	*0.004456*	*0.95496*		2.2882	0.514784	
Energy-related factors							
nuclear_percent	The percentage of domestic energy production from nuclear power	*0.432296*	*2E-16*	***	17.0769	0.000682	***
renew_percent	The percentage of domestic energy production from renewables	*−0.203*	*0.00271*	**	8.1785	0.042463	*
oil_price	Oil price	*−0.14062*	*0.01826*	*	3.6157	0.306064	
Natural and technological risk factors							
seismic_stability	Seismic stability of bedrock in the country	*0.132876*	*8.51E-07*	***	14.2079	0.002635	**
eq_1900_int	The average frequency of significant earthquakes since 1900	*0.06981*	*0.05484*		20.5176	0.000133	***
tmi_impact	Estimated impacts of the major nuclear accidents on public acceptance	*1.280845*	*0.20408*		2.6118	0.455416	
chernobyl_impact		*−0.20126*	*0.24275*		0.8615	0.834708	
fukushima_impact		*0.116072*	*0.24617*		5.9812	0.112528	

p < 0.1; * p < 0.05; ** p < 0.01; *** p < 0.001.

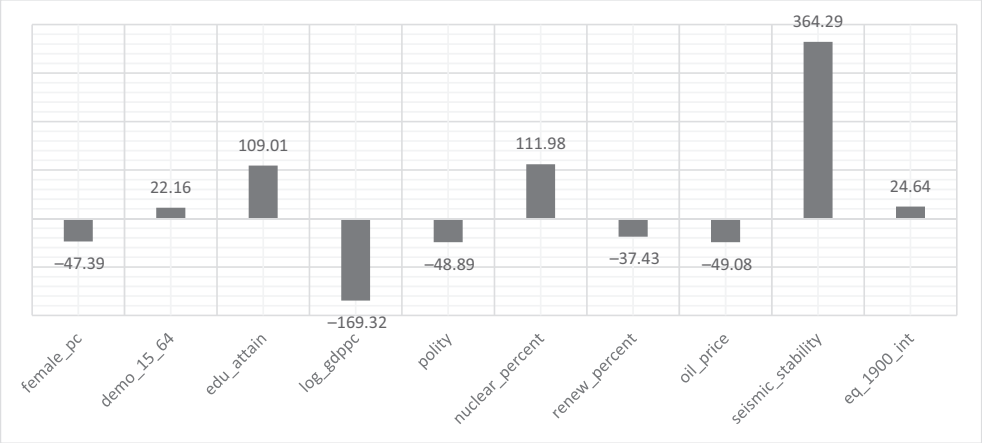

Fig. 1. Substantive effects of the statistically significant variables on nuclear acceptance (in percentages).

4.2. Implications

As shown in Fig. 1, both Hypotheses 1 and 2 were verified by the public nuclear acceptance data set. While the negative impact of socioeconomic factors like *female_pc* (the proportion of females in the total population), *log_gdppc* (gross domestic product (GDP) per capita in logarithmic scale), or *polity* (democracy level) is foreseeable given the consensus of academic literature on these issues, the significant and positive effect of average years of continuous education (*edu_attain)* is noticeable as there have been studies supporting a negative correlation between the level of education of the public and their nuclear acceptance [31]. This seemingly causal relation is important from the policy-making standpoint, as different from factors like *female_pc* or *log_gdppc;* the improvement of *edu_attain* may be attained through careful development of education and communication strategies. On the other hand, the lack of correlation between *press_score* and the overall nuclear acceptance could be due to the subjective bias of the scoring agency or the fact that the media impact is heavily affected by political orientation, which was not quantified in this model. Nevertheless, the negative significances of the democracy-related variable (*polity*) and the living standard variable (*log_gdppc*) point to the generally irreversible trend in which public opposition against nuclear energy often increases with the economic growth and democratization of the society. This indicated that the introduction of nuclear energy would become difficult once the living standard and the freedom of the society improve in aspiring states.

The inverse relationship between *nuclear_percent* (the percentage of domestic energy production from nuclear power) and *renew_percent (*the percentage of domestic energy production from renewables) with *support_net*, as was indicated in Fig. 1, helped verify Hypothesis 3 and confirmed the proposition in Section 2 that people in nuclear power countries tend to have better acceptance of nuclear energy than the residents of countries without that type of energy. It is necessary to note, however, that the causal direction between *renew_percent* and *support_net* can also be reversed, in the sense that lower public acceptance of nuclear energy pushes the authority to favor alternative options such as renewable energy. On the other hand, the negative correlation between *oil_price* (oil price) and *support_net* contradicts the arguments presented in Section 2.2 about the trilateral relation between oil prices, energy security, and public acceptance of nuclear energy. This contradiction may come from the fact that the arguments were based on the rapid expansion of the nuclear industry after the 1970s oil crises, whereas the data set used in this study only covered from 1987 onward.

Finally, the positive relation between the existence of suitable geological conditions and the public acceptance of nuclear energy, as was noted by Hypothesis 4, is supported by the strong substantive effect of *seismis_stability* (seismic stability of bedrock in the country) and *support_net*. On the other hand, the direct correlation between *eq_1900_int* (the average frequency of major earthquakes since 1900) and *support_net* might be explained by the fact that many countries that use nuclear power can be considered to contain seismically active regions in their land because of their vast territory, that is, the US, Russia, Canada, and China. In general, the governments of countries with seismic concerns should carefully consider the decision to go nuclear, as they would likely face unfavorable public sentiment. The lack of significant correlation between the level of nuclear public acceptance and accident-related variables shows that the use of the exponential Formula (3) to represent the psychological impact of nuclear accidents might not be appropriate. Moreover, there are arguments that the impact of nuclear accidents on new NPP construction dates, which are highly correlated with the public reception of nuclear energy at such dates, varies between the accidents and among different countries [17]. Therefore, accident- and country-specific formulas may need to be developed in future studies.

4.3. Potential weaknesses of the study

The public opinion surveys used in this study come from various sources, and thus they may have different degrees of data quality. In addition, it should be noted that the ambivalence in people's opinions on a complex subject like nuclear energy is very difficult to be quantified through public surveys, and thus remains a significant issue in the study of nuclear acceptance. Specifically, the meaning of actual opinions may be lost in a dichotomous categorization of opinion or by different ways of framing questions [19]. For example, results of a survey conducted by a Taiwanese newspaper with a sympathetic view of the government in 2012 painted a significantly better picture of nuclear acceptance in comparison with the findings by another outlet without such political preference [32]. Consequently, a general formula like (1) may not fully address such nuances in the outcome of public surveys on nuclear energy.

Public opinion surveys are by nature heavily influenced by the opinions of others, especially when the necessity of nuclear energy is a contested subject without a predefined “right” answer. Therefore, survey results may only reflect the convergence of personal ideas and could create inaccuracies in the evaluation and prediction of future trends of public opinion. Furthermore, the roles of the

political parties, for which the preferences for nuclear energy are different, and pronuclear or antinuclear organizations in forming public attitudes on nuclear issues were not discussed in this article. The absence of such discussion is due to the lack of systematic data and not due to its importance because the dynamics between these key players definitely influence nuclear acceptance in numerous states, especially in the case of lacking sufficient nuclear knowledge.

The potential negative outcome in the long-term psychological impact of nuclear accidents on the public acceptance of nuclear energy needs further investigation. Despite its complexity, however, it is essential to study such impact in future studies. Finally, despite the lack of statistical collinearity between independent variables, there likely exists a causal relationship between the socioeconomic factors. For the purpose of simplification, such complex relationship was not addressed in this article. Such causality needs to be examined in future studies to clarify the dynamics between social conditions and public acceptance of nuclear energy.

5. Conclusions

Common patterns of nuclear public acceptance were examined through the review of available literature from different countries. Based on these patterns, hypotheses on the impact of different socioeconomic factors on the public opinion of nuclear energy were proposed and tested using a cross-country data set of nuclear public acceptance. Results of a regression analysis generally verified the proposed hypotheses. In particular, we noted the positive impact of education and the seismic stability of a nation's bedrock or the negative effect of improved living standards and democracy on nuclear public acceptance. Our results indicated that well-coordinated efforts in education and communication could make an impact on public nuclear acceptance. The results also indicated that for a country to make a decision to go nuclear, a thorough consideration of the social and geological conditions of the country should be made to ensure the sustained public support for such a project. As risk perception in general and the public acceptance of nuclear energy in particular contain numerous nuances and irregularities, potential weaknesses of this study were also noted and discussed, including the possible causal relation between independent variables or a weakness in the use of the binary data for the dependent variable. In addition, because people in countries with and without NPPs have very different perceptions of the actual benefits from the operation of such plants, in future studies related to the nuclear acceptance data set presented in this article, these two categories of countries can also be examined separately for a better understanding of the impact of the benefits from nuclear energy. In such future studies, further refinement of the set of independent variables should also be considered to identify the most meaningful factors affecting the public opinion on nuclear energy so that effective policy recommendations can be made for evaluating the possible level of nuclear acceptance before a nuclear power program is initiated, and for securing such acceptance during the construction and operation of NPPs. Despite these issues, however, the findings of this cross-country, longitudinal study are still useful for the designing future research on nuclear public acceptance. Such studies provide a holistic view of this subject and are important not only for future public communication efforts, but also for better academic understanding of risk perception in general.

Finally, it is clear that the development of a nuclear acceptance data set is a delicate process as survey results heavily depend on the framing of the survey questions, which are often different from country to country, and survey to survey. Nevertheless, this model will serve as a useful tool for the nuclear policy studies on public acceptance of nuclear energy and in particular of introduction of nuclear power.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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