Nuclear Engineering and Technology 54 (2022) 3695–3702

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

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

Original Article

Nuclear power in jeopardy: The negative relationships between greenhouse gas/fine dust concerns and nuclear power acceptance in South Korea

Jin Won Lee [a], Seungkook Roh [b, *]

[a] Marketing Department, School of Business Administration, Jimei University, Xiamen, 361021, China
[b] Department of Public Administration, Korean National Police University, Asan, 31539, Republic of Korea

ARTICLE INFO

Article history:
Received 20 July 2021
Received in revised form
21 April 2022
Accepted 30 May 2022
Available online 16 June 2022

Keywords:
Greenhouse gases
Fine dust
Nuclear power
Public acceptance
Environmental value
Public communication
Korea

ABSTRACT

South Korea, a country that built a world-class nuclear power infrastructure, shifted to a nuclear phase-out during the previous government's reign. This shift was pursued as part of a larger task of electricity mix reform, and one of the integral motives for such reform is addressing greenhouse gas (GHG) and fine dust problems. Thus, verifying the relationships between the public's concerns about GHG/fine dust and their acceptance of nuclear power generation is essential for designing public communication strategies to revive nuclear power under the ongoing environmental regime. Our analysis using a nationwide survey sample of South Korea (N = 1009, through proportionated quota sampling method) showed that the more people are concerned about GHG and fine dust, the less they accept nuclear power. These relationships held even after controlling for the effect of a third variable—energy-related environmentalism. This finding means that despite past communication efforts positioning nuclear power as a generation source that can mitigate GHG/fine dust emissions and the widely accepted scientific evidence that supports such positioning, nuclear power in Korea is in jeopardy. Our finding provides implications for public communications and fundamental knowledge for research on the determinants of nuclear power acceptance.

1. Introduction

South Korea (hereafter, Korea) is one of the countries where the status of nuclear power has been dramatically changing in the last few years. In 2016, Korea ranked fourth in the world for the number of nuclear power plants; 13th for the proportion of nuclear power in electricity mix—the combination of primary sources to generate electricity [1]. However, the Moon Jae-in government, inaugurated in 2017, pushed ahead with a nuclear phase-out [2–4]. More recently, Yoon Suk-yeol's new government is pushing for the withdrawal of the nuclear phase-out [5]. This series of shifts in national stance over nuclear power constantly caused fierce controversies in Korean society [6–10], implying a firm revival of nuclear power in Korea requires continuous communication to enhance acceptance of nuclear power generation among the public—a significant influencer on energy policy [11,12].

The former government's pursuit of the nuclear phase-out in Korea was part of a larger task of electricity mix reform—phasing out coal and nuclear power while expanding natural gas and new renewable energy in the electricity mix. Thus, in Korea, the revival of nuclear power means easing the pace of expansion of new renewable energy [2,13]. In this respect, appealing to certain significant motives for expanding new renewable energy met by nuclear power would help boost public support for nuclear revival by weakening the legitimacy of the rapid expansion of new renewable energy.

Among the various and complex motives for the Korean public to support new renewable energy, an integral one is addressing environmental problems [3,4]: greenhouse gases (GHGs) and fine dust. In Korea, like over the globe, new renewable energy has been positioned as an electricity generation source that reduces GHG emissions [14], which are the main cause of human-induced climate change [15]. The other issue considered here—the fine dust problem—feels more relevant to Korean people's everyday lives [16]: fine dust causes various physical problems such as

* Corresponding author.
E-mail addresses: nevermean@empas.com (J.W. Lee), skroh@police.ac.kr (S. Roh).

https://doi.org/10.1016/j.net.2022.05.032

respiratory disease, headache, eye disease, and visual shocks. In Korea, public concerns regarding fine dust have been rapidly rising, particularly during the last decade [17]. The reduction of fine dust emerged as one of the hottest issues in the 2017 presidential election [18]. Coal power generation is one of the main sources of fine dust emissions in Korea [19]. In contrast, new renewable energy is a generation source with low fine dust emissions. Thus, expanding new renewable energy has been framed as a way to mitigate fine dust emissions in Korea [20].

However, one thing to note is that new renewable energy is not the only generation source that tackles the two problems above: GHG and fine dust emissions of nuclear power generation are also extremely low [21–23]. The more serious people's concern about a certain problem, the more favorable their response to a solution addressing that problem [24–27]. Thus, it seems intuitive at first glance that the public's concerns about GHG and fine dust problems would lead them to greater acceptance of nuclear power generation. However, whether this common-sense reasoning fits well needs confirmation. For example, some previous studies found that those who are more concerned about climate change may not necessarily respond to nuclear power more positively [28–30].

The signs (i.e., positive or negative) of those relationships provide basic knowledge regarding effective public communication strategies for nuclear power. Such signs enable us to diagnose whether the public recognizes nuclear power as a method to mitigate GHG and fine dust emissions during generation. Furthermore, depending on such signs, the focus and priority of public communication efforts can vary. For example, if such relationships are positive and reflect causal relationships, it implies that stimulating the public's concern about either GHG or fine dust may help improve their acceptance of nuclear power generation. However, it is difficult to find a study targeting the Korean public to investigate the above relationships and derive the direction of the public communication strategy for enhancing nuclear power acceptance based on the research results. In addition, studies reflecting the relationship between concern about fine dust and nuclear power acceptance in the research model are difficult to find in Korea and other countries.

Prompted by this research need, the present study investigates the relationships between the Korean people's concerns about GHG and fine dust and their acceptance of nuclear power generation. In verifying such relationships, we control for the effect of a potential third variable [31,32] that reflects an individual's pro-environmentalism. Such a variable could positively affect GHG and fine dust concerns while negatively affecting nuclear power acceptance [29,33,34], thereby rendering the relationships of our interest biased.

The subsequent sections, Theoretical bases and Analysis strategy, detail our theoretical bases and derived analysis models. The Methodology section describes the sample and variables of interest. In the Results section, using a nationwide survey sample of Korea, we found that (1) people's concerns about GHG and fine dust had negative relationships with their acceptance of nuclear power generation and (2) such relationships remained negative even after controlling for the effect of a pro-environmentalism variable (i.e., energy-related environmentalism). The Discussion section provides implications to be considered by energy scholars and practitioners. The Conclusion section summarizes the finding and suggests future research directions.

2. Theoretical bases

2.1. The relationship between environmental concern and nuclear power acceptance

The more serious people perceive a certain problem, the more favorable they should be to an alternative addressing that problem [24–27]. Consistent with this notion, studies combining the norm activation model (NAM) and the theory of planned behavior (TPB) showed that an individual's awareness of a problem (a major factor in the NAM) positively influences their attitude toward an object (a major factor in the TPB) that is congruent with the problem's mitigation or solution (e.g. Refs. [27,35–37]).

A widely accepted scientific fact is that GHG and fine dust emissions of nuclear power generation are extremely low [38]. Considering this scientific fact and the previous findings on the effect of problem awareness on attitude toward the solution, people's concerns about GHG and fine dust should lead to their acceptance of nuclear power generation. Regarding concern about GHG, some existing studies showed consistent findings with this common-sense relationship (e.g. Ref. [39]); however, several others found the reverse—those who are more concerned about climate change tend to respond to nuclear power more negatively (e.g. Refs. [28,29,33,40]). In contrast to this research attention, investigations of the relationship between concern about fine dust and nuclear power acceptance are difficult to find, probably because the fine dust problem is not as global an issue as the GHG problem.

2.2. Environmental value as an antecedent of environmental concern

An individual's values may act as filters: they may lead the individual to seek information selectively and be more aware of the seriousness of consequences of a particular object that is dissonant with them [41]. Consistent with this view, the value-belief-norm (VBN) theory of environmentalism postulates that an individual's values influence their pro-environmental beliefs and personal norms, affecting their pro-environmental behavior [42,43]. Many empirical studies that adopted the VBN theory showed that value significantly predicts problem awareness. For example, regarding environmentally friendly values, several studies found that pro-environmental values such as ecocentrism, environmental worldviews, or biospheric value increase awareness of the negative consequences of environmental problems (e.g. Refs. [44–48]). Furthermore, in the context of nuclear power acceptance, Whitfield et al. [49] found that altruistic values, several of whose items were about the degree of valuing nature and environment, are a significant positive predictor of new ecological paradigms, which correspond to a variable of environmental concern. These findings indicate that people with environmentally friendly values are likely to have a higher level of environmental concern, meaning that they take environmental problems more seriously.

2.3. Environmental value as an antecedent of nuclear power acceptance

An individual's values on different targets direct their attention toward value-congruent information, which in turn affects their attitudes toward the targets [50]. Thus, one's values are an important determinant of their acceptance of the generation source [51]. Among those values, environmental values exert differentiated effects on attitudes toward different generation sources [34]. For example, previous research found that people with strong environmental values favor new renewable energy [52] and show less favor, support, or acceptance of nuclear power generation [33,49,50]. This can be attributed to the fact that nuclear power's risks of radioactive contamination and accidental nuclear disasters is not consonant with pro-environmental values [29,33].

3. Analysis strategy

3.1. The relationships between GHG/fines dust concerns and nuclear power acceptance

As noted in sections 1 and 2.1, the relationship between environmental concern and nuclear power acceptance needs investigation. Thus, we examine the relationships between concerns about GHG and fine dust and acceptance of nuclear power generation. To avoid a suppression effect [53], we examine these two relationships using separate regression models:

$$Acc_{Nuc} = a_1 + \beta_{11}Con_{GHG} + \beta_{12}Gen + \beta_{13}Age + \varepsilon_1 \quad (1)$$

$$Acc_{Nuc} = a_2 + \beta_{21}Con_{FD} + \beta_{22}Gen + \beta_{23}Age + \varepsilon_2 \quad (2)$$

where

Acc_{Nuc} = the respondent's acceptance of nuclear power generation,
Con_{GHG} = the respondent's concern about GHG,
Con_{FD} = the respondent's concern about fine dust,
Gen = the respondent's gender,
Age = the respondent's age,
a_j = constant term,
ε_j = error term.

3.2. Environmental value as a third variable in the concern–acceptance relationships

As noted in section 2.2, environmental value is likely a positive antecedent of environmental concern. Considering this, a variable that reflects an individual's pro-environmentalism is likely to be an antecedent of concerns about GHG and fine dust—specific forms of environmental concern. In addition, according to section 2.3, such a pro-environmentalism variable is likely to be a negative antecedent of nuclear power acceptance. Thus, such a variable is likely to correspond to a third variable in the relationships between the concern variables and the acceptance variable. The omission of this third variable can result in a bias in estimating the relationships [31,32]. Thus, it is necessary to control for the effect of a pro-environmentalism variable to increase understanding regarding the relationships between concerns about GHG/fine dust and nuclear power acceptance among the Korean public.

For such a pro-environmentalism variable, we need a variable specified in the context of energy acceptance—a variable showing which among environmental and economic aspects an individual values more highly when evaluating/accepting a generation source. We refer to this variable as energy-related environmentalism. At this step, we examine the predictive validity of this proposed third variable. First, we will test whether energy-related environmentalism positively influences concerns about GHG and fine dust, through a bivariate regression [54] as follows:

$$Con_{GHG} = a_3 + \beta_{31}EE + \beta_{32}Gen + \beta_{33}Age + \varepsilon_3 \quad (3)$$

$$Con_{FD} = a_4 + \beta_{41}EE + \beta_{42}Gen + \beta_{43}Age + \varepsilon_4 \quad (4)$$

where

EE = energy-related environmentalism,
error terms ε_3 and ε_4 are correlated.

Second, we will check whether energy-related environmentalism is predictive of the acceptance variables of general generation sources—nuclear power, coal power, and new renewable energy. Extant studies found that people with environmentally friendly values tend to be less supportive of fossil power and nuclear power and more supportive of new renewable energy (e.g. Refs. [29,33,34,55]). Thus, we will run a multivariate regression as follows:

$$Acc_{Nuc} = a_5 + \beta_{51}EE + \beta_{52}Gen + \beta_{53}Age + \varepsilon_5 \quad (5)$$

$$Acc_{Coal} = a_6 + \beta_{61}EE + \beta_{62}Gen + \beta_{63}Age + \varepsilon_6 \quad (6)$$

$$Acc_{NRE} = a_7 + \beta_{71}EE + \beta_{72}Gen + \beta_{73}Age + \varepsilon_7 \quad (7)$$

where

Acc_{Coal} = acceptance of coal power generation,
Acc_{NRE} = acceptance of new renewable energy generation,
error terms ε_5 to ε_7 are correlated.

3.3. Controlling for the effect of the proposed third variable in the concern–acceptance relationships

Suppose that we find energy-related environmentalism is a third variable affecting both (1) GHG and fine dust concerns and (2) acceptances of nuclear power, coal power, and new renewable energy. In this case, we will examine the relationships between such concerns and nuclear power acceptance while controlling for the effect of this third variable by including the third variable in the regression models [56,57] as follows:

$$Acc_{Nuc} = a_8 + \beta_{81}Con_{GHG} + \beta_{82}EE + \beta_{83}Gen + \beta_{84}Age + \varepsilon_8 \quad (8)$$

$$Acc_{Nuc} = a_9 + \beta_{91}Con_{FD} + \beta_{92}EE + \beta_{93}Gen + \beta_{94}Age + \varepsilon_9 \quad (9)$$

4. Methodology

4.1. Sample and data collection

The study used a dataset built by the Hyundai Research Institute [58], an economic research institute in Korea. The survey was carried out in May of 2018, the year after the launch of the Moon government and its nuclear phase-out policy. The survey targeted the Korean population 20 years old and older through telephone interviews. The data collection was outsourced to a professional opinion research firm. The sampling adopted proportionated quota sampling method [59] and considered the population sizes by region, gender, and age. The proportions of quotas were set based on the resident registration population as given by the Korean Ministry of Government Administration and Home Affairs in September of 2017. The interviewers contacted the respondents through landline random digit dialing. The survey collected data from 1009 respondents: the confidence level was 95%, and the margin of error was ±3.1% points. Table 1 shows profiles of the study sample (N = 1009).

4.2. Measures

4.2.1. Main independent variables

In the environmental literature, researchers frequently measure problem awareness by asking about the degree to which the respondent is aware of the negative consequences of practice

Table 1
Sample profile.

Variable	Description	Distribution	
Gender	Respondent's gender	Male	50.64%
		Female	49.36%
Age	Respondent's age (measured in specific age)	20–29	18.43%
		30–39	18.44%
		40–49	21.80%
		50–59	20.32%
		60+	21.01%
Area	Respondent's residential area	Seoul	20.81%
		Busan	7.43%
		Daegu	5.15%
		Incheon	5.35%
		Gwangju	3.07%
		Daejeon	3.07%
		Ulsan	2.18%
		Gyeonggi Province	21.70%
		Gangwon Province	3.27%
		Chungcheongbuk Province	3.17%
		Chungcheongnam Province	3.96%
		Jeollabuk Province	3.67%
		Jeollanam Province	3.96%
		Gyeongsangbuk Province	5.45%
		Gyeongsangnam Province	6.54%
		Jeju Province	1.19%

Note. $N = 1009$.

without countermeasures or precautions: for example, negative consequences from current delivery methods [35], a specific industry [37], etc. Similarly, energy literature measures concern about climate change (alternatively called the perception of climate change, perception of the seriousness of climate change, etc.) by asking about the respondents' perceived seriousness of consequences of GHG emissions (e.g. Refs. [28,29,33]). Consistent with this, the present study's survey measured respondents' concern about GHG as follows: "What do you think about the social cost of greenhouse gas emissions that causes global warming?" (1 = "very high"; 2 = "somehow high"; 3 = "normal"; 4 = "somehow low"; 5 = "very low"). Concern about fine dust was also assessed: "What do you think about the social cost of fine dust emissions?" (1 = "very high"; 2 = "somehow high"; 3 = "normal"; 4 = "somehow low"; 5 = "very low"). The answers to both items were reverse-coded.

4.2.2. Dependent variable

Acceptance of nuclear power generation measured the respondents' opinion on the desirable portion of nuclear power in the country's electricity generation [60,61]. The item asked the respondents the following question: "What do you think the proportion of nuclear power for electricity generation should be?" (1 = "should be reduced drastically"; 2 = "should be reduced gradually"; 3 = "should be maintained at the current level"; 4 = "should be expanded gradually"; 5 = "should be expanded drastically").

4.2.3. The third variable

A prevalent way to measure an individual's environmentalism is by asking about the degree to which the individual values the environment or nature (e.g. Refs. [44–48]). In the context of energy policy, the present study's survey measured the respondents' energy-related environmentalism by asking about which they value more between environmental protection and cost efficiency regarding the country's energy policy. The item ("Which of the following energy policy criteria do you agree with the most?") used a three-point scale (1 = "even if generation costs increase, electricity from energy sources that do not threaten the environment and safety should be supplied first"; 2 = "even if it threatens the environment and safety, electricity made from energy sources that cost less should be supplied first"; 3 = "electricity should be supplied by considering both the impact on the environment and safety, and the cost of energy sources together"). Responses were re-coded so that a greater score represents a higher level of energy-related environmentalism (i.e., 1, 2, 3 re-coded as 3, 1, 2, respectively).

4.2.4. Other variables

The survey measured acceptances of coal power and new renewable energy consistent with nuclear power, using the following questions (one version for each energy source): "What do you think the proportion of [energy source] for electricity generation should be?" (1 = "should be reduced drastically"; 2 = "should be reduced gradually"; 3 = "should be maintained at the current level"; 4 = "should be expanded gradually"; 5 = "should be expanded drastically"). In addition, demographic variables such as the respondent's gender (contrast-coded: male = −1; female = 1), age, and area were measured. Table 2 shows correlations and descriptive statistics of the key variables. We used Stata version 15 for all the statistical analyses hereafter.

5. Results

5.1. The relationships between GHG and fine dust concerns and nuclear power acceptance

As Table 3 shows, both GHG concern and fine dust concern had a significant negative relationship with nuclear power acceptance

Table 2
Correlations and descriptive statistics of key variables.

Variable	a	b	c	d	e	f
a. EE						
b. Con_{GHG}	0.10**					
c. Con_{FD}	0.10**	0.63***				
d. Acc_{Nuc}	−0.22***	−0.17***	−0.19***			
e. Acc_{Coal}	−0.13***	−0.19***	−0.18***	0.31***		
f. Acc_{NRE}	0.16***	0.17***	0.12***	−0.26***	−0.19***	
Mean	2.25	3.94	4.00	2.30	2.00	4.07
Standard deviation	0.60	0.97	0.98	0.84	0.75	0.79

Note. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. EE = energy-related environmentalism; Con_{GHG} = concern about GHG; Con_{FD} = concern about fine dust; Acc_{Nuc} = acceptance of nuclear power; Acc_{Coal} = acceptance of coal power; Acc_{NRE} = acceptance of new renewable energy. EE used a three-point scale ranging from 1 to 3; the other variables used a five-point scale ranging from 1 to 5.

Table 3
Regression coefficients for acceptance of nuclear power generation.

Independent variables	Dependent variable: Acc_{Nuc}†			
Gen	−0.07 (0.03)*	−0.07 (0.03)*	−0.07 (0.03)*	−0.07 (0.03)*
Age†	0.17 (0.03)***	0.17 (0.03)***	0.16 (0.03)***	0.16 (0.03)***
Con_{GHG}†	−0.19 (0.03)***	−0.17 (0.03)***		
Con_{FD}†			−0.19 (0.03)***	−0.17 (0.03)***
EE†		−0.20 (0.03)***		−0.20 (0.03)***
Model F	22.41***	28.34***	24.08***	30.16***
R^2	0.07	0.11	0.07	0.11

Note. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Acc_{Nuc} = acceptance of nuclear power; Gen = gender; Age = age; Con_{GHG} = concern about GHG; Con_{FD} = concern about fine dust; EE = energy-related environmentalism. † The variable has been standardized.

(standardized $\beta_{11} = -0.19$, $t = -5.94$, $p < 0.001$; standardized $\beta_{21} = -0.19$, $t = -6.25$, $p < 0.001$), when the effect of energy-related environmentalism was not controlled for.

5.2. The relationships between GHG and fine dust concerns and nuclear power acceptance when the effect of the third variable is controlled for

5.2.1. The predictive validity of the third variable

Energy-related environmentalism was found to have a significant positive effect on concern about GHG (standardized $\beta_{31} = 0.10$, $t = 3.17$, $p < 0.01$) and that about fine dust (standardized $\beta_{41} = 0.11$, $t = 3.36$, $p < 0.01$). These mean that individuals with a greater level of environmentalism regarding energy tend to take GHG and fine dust emissions more seriously.

Energy-related environmentalism was found to have a significant negative effect on acceptance of nuclear power generation (standardized $\beta_{51} = -0.22$, $t = -7.16$, $p < 0.001$) and that of coal power generation (standardized $\beta_{61} = -0.14$, $t = -4.33$, $p < 0.001$) but a significant positive effect on acceptance of new renewable energy generation (standardized $\beta_{71} = 0.16$, $t = 5.06$, $p < 0.001$). These effects are consistent with the previous findings that people with pro-environmental value accept new renewable energy but tend to reject fossil power or nuclear power [33,34,55]. Therefore, we can state that our proposed third variable (i.e., energy-related environmentalism) has a predictive validity: its effects on acceptances of different types of generation sources are consistent with the theoretical prediction.

Overall, energy-related environmentalism was found to have a significant positive effect on our main independent variables (GHG concern and fine dust concern) and a significant negative effect on our main dependent variable (nuclear power acceptance). Thus, we need to control for the effect of energy-related environmentalism in the relationships between the main independent variables and the main dependent variable.

5.2.2. Controlling for the effect of the third variable

The left half of Table 3 and Fig. 1a compare the relationship between GHG concern and nuclear power acceptance when the third variable effect of energy-related environmentalism was uncontrolled and controlled. We tested the strength of the third variable effect using bootstrapping [62]. Energy-related environmentalism only partially explained the negative relationship between GHG concern and nuclear power acceptance ($\Delta\beta = -0.02$, $z = -2.55$, $p < 0.05$). Even when controlling for the effect of energy-related environmentalism, the relationship remained significantly negative (standardized $\beta_{81} = -0.17$, $t = -5.51$, $p < 0.001$).

These results were similar regarding the relationship between fine dust concern and nuclear power acceptance, as illustrated in the right half of Table 3 and Fig. 1b. Energy-related environmentalism only partially explained the negative relationship between fine dust concern and nuclear power acceptance ($\Delta\beta = -0.02$, $z = -2.59$, $p < 0.01$). The relationship remained significantly negative (standardized $\beta_{91} = -0.17$, $t = -5.75$, $p < 0.001$) even when controlling for the effect of energy-related environmentalism.

Overall, the negative relationship between concern about GHG and nuclear power acceptance (see Fig. 1a) and that between concern about fine dust and nuclear power acceptance (see Fig. 1b) cannot be wholly attributed to the proposed third variable (i.e., energy-related environmentalism). Therefore, we cannot rule out a possibility that such negative relationships are causal relationships between the concern variables and the acceptance variable.

6. Discussion

6.1. Possible underlying mechanisms of the finding

Our analysis revealed that whereas Korean people with greater concerns about GHG/fine dust may oppose nuclear power partially based on their strong pro-environmental value, they may reject the power for other reasons. Our statistical results do not directly reveal these 'other' reasons. However, combining our results with extant studies implies some possibilities.

First, the above negative relationships may be rooted in the Korean public's insufficient knowledge regarding nuclear power. Chung and Kim [28] found that a larger portion of the Korean public (43%) agree that nuclear power generation exacerbates climate change (34% "disagree" and 24% "do not know"). These authors also introduced similar results from a survey conducted by the Korea Nuclear Energy Agency (KNEA) in 2015: 54.2% of respondents perceived nuclear power as not contributing to "solving the climate change problem" [28]. This public notion of nuclear power may also be true for fine dust. For instance, if they lacked knowledge about nuclear power, thus misunderstanding that nuclear power accelerates GHG emissions, such a lack of knowledge may also lead to a misunderstanding that the power also accelerates fine dust emissions. If this is the case, the consequence can be: the more concerned about GHG and fine dust emissions, the lower their level of nuclear power acceptance.

Second, there is a possibility that people who are concerned about GHG and fine dust emissions make judgments about nuclear power using their environmentally friendly heuristics rather than seriously considering the relationship between such emissions and nuclear power. That is, rather than using rational and systematic analysis of the consequences of nuclear power, people may use analytic "short cuts" drawing from existing beliefs and emotions tied to prior experiences [63,64]. There are associations between nuclear power and environmentally negative keywords, such as nuclear weapons and explosions [63,65]. The media reinforce these

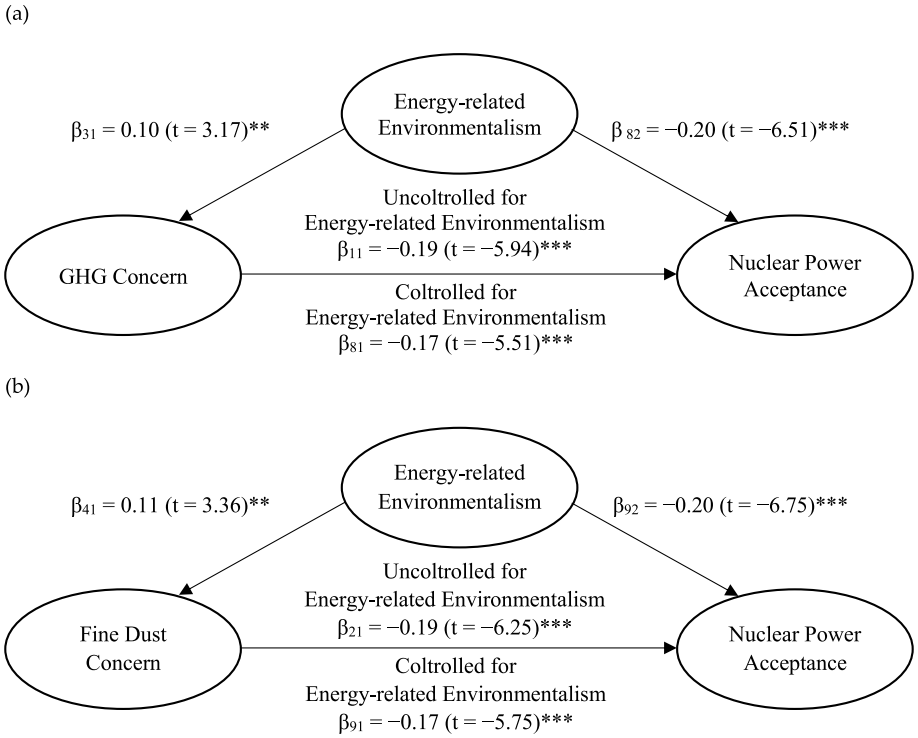

Fig. 1. Energy-related environmentalism as a third variable in the relationships between the concern variables and nuclear power acceptance. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Coefficients are standardized ones.

associations. For example, one of the most representative images of nuclear power is that of mushroom clouds. As a result, nuclear power, radioactive isotopes in medical use, and nuclear weapons remain interconnected in most people's minds, although these technologies have separate infrastructures [63,66]. Under these associations, it is not surprising that people concerned about GHG and fine dust, which reflects their concerns about safety and health, have a negative attitude toward nuclear power.

6.2. Policy implications

No matter which of the possibilities we raised above is closest to the specific underlying mechanism of our finding, the finding means that nuclear power in Korea is in jeopardy despite the widely accepted scientific evidence that nuclear power is a generation source that can mitigate GHG/fine dust emissions [21–23]. Detailed emphasis can vary subtly depending on the above possibilities in addressing this jeopardy.

First, if it is the case that the negative relationships between GHG/fine dust concerns and nuclear power acceptance reflect the people's incorrect or insufficient knowledge about nuclear power's environmental contributions, then improving such public knowledge should be given the priority, on the following grounds. The effect of public perception of nuclear power's contributions to reducing GHG emissions on nuclear power acceptance is found to be consistently positive in several studies from Korea and abroad (e.g. Ref. [67,68]). In addition, previous research abroad has provided some evidence that nuclear power acceptance is increased when the power is explicitly framed as a potential method of mitigating climate change (e.g. Ref. [33,69]). Thus, it can be inferred: once people in Korea have the correct knowledge that nuclear power generation can reduce GHG and fine dust emissions, they will be more likely to accept nuclear power. These research findings and reasoning indicate that the pro-nuclear sides need to focus on disseminating scientific knowledge about the environmental benefits of nuclear power and regular and careful monitoring of the consequences of such efforts. Particularly, in our analyses, the negative relationships between GHG/fine dust concerns and nuclear power acceptance remained negative even after controlling for the effect of the likely third variable—energy-related environmentalism. Therefore, we should not rule out the possibility that these negative relationships are negative causality. In the presence of such a negative causal relationship, solely evoking the severity of the GHG/fine dust problems without sufficiently enhancing public knowledge of nuclear power's mitigation of such problems would negatively affect public acceptance of nuclear power generation.

Second, suppose that our finding of the negative relationships is rooted in people's heuristic judgments about nuclear power. In that instance, the communication strategies need to consider the following: (1) bringing the public judgment of nuclear power into the realm of rational judgment, not heuristics, (2) blocking the source of public heuristic judgments that are unfriendly to nuclear power, and (3) inducing the public's heuristic judgments to work in favor of nuclear power, or all or any of them. The first and second strategies above would continuously provide the public with scientific knowledge of the safety of nuclear power, which several studies suggest (e.g. Ref. [70]), in a variety of easy-to-understand information. Although the specific mechanisms of heuristic judgments are various, their common motivation is to ease the cognitive load of judgment, which increases not only when the relevant information is complex but also when the information is less available [63]. Thus, information delivering scientific facts about the safety of nuclear power should be structured so that the public can understand such information with less cognitive load. The third strategy is a sort of "heuristic for heuristic" approach. An example of a heuristic that can elicit a positive response to nuclear power is the "trust heuristic:" the

argument from a trustworthy authority provides the public with a plausible reason to follow such an argument [64,71]. Therefore, one of the urgent tasks for pro-nuclear groups in Korea would be gaining the public's trust. In addition, examples of countries that are expanding or have withdrawn nuclear phase-out policy among the world's major developed countries can also serve as heuristics to induce a positive response to nuclear power.

7. Conclusion

Our analysis using a nationwide survey sample of Korea showed that the more people are concerned about GHG and fine dust, the less they accept nuclear power. These relationships remained negative even after controlling for the effect of a third variable—energy-related environmentalism. This finding means that despite past communication efforts positioning nuclear power as a generation source that can mitigate GHG/fine dust emissions [72,73] and the widely accepted scientific evidence that supports such positioning [21–23], nuclear power in Korea is in jeopardy. In connection with the findings from previous studies, we discussed possible underlying mechanisms of such counter-intuitive finding. We suggested a couple of guidelines for public positioning strategies for nuclear power in Korea, considering the discussed possibilities.

Our finding is also alarming to other countries operating or pursuing nuclear power plants. Korea, before its previous government of Moon Jae-in, was a country that nationally promoted nuclear power generation as a pro-environmental generation source [72,73]. If this positioning is poorly accepted in a country like Korea, we cannot rule out the possibility that such positioning is also poorly accepted in other countries. This possibility implies that nuclear power may be in jeopardy not only in Korea but also in other countries.

The present study also has the following limitations. First, it did not directly measure people's knowledge or perception of whether nuclear power mitigates GHG/fine dust emissions. Thus, future surveys on the determinants of nuclear power acceptance need to include both of the following kinds of variables: (1) variables on the respondents' concerns about GHG/fine dust emissions and (2) those on the respondents' knowledge/perception on nuclear power's benefits in mitigating such emissions. Then, research could be done to compare the relationships between the concern variables and nuclear power acceptance between a group with a low level of knowledge/perception on nuclear power's benefits and a group with a high level of such knowledge/perception. Thereby, clearer and more decisive evidence could be found on whether nuclear power is on false charges and whether such false charges are inverting the intuitive relationships between GHG/fine dust concerns and nuclear power acceptance.

Second, several other factors on nuclear power acceptance are missing in the present study: for example (1) perceptions of nuclear power's benefits (e.g., economic benefits and environmental benefits [74]), (2) risks (e.g., risks of chronic radiation and accidental nuclear catastrophe [75]), and (3) environmental concern variables that can specifically affect these benefit and/or risk perceptions. As noted in section 6.1 and according to the trust-acceptability model and the benefit-risk framework, perception of risk from nuclear power negatively influences nuclear power acceptance [11,61,76]. In addition, Hu et al. [39] proposed perceptions regarding nuclear power as mediators between environmental concern and nuclear power acceptance. Thus, there is a strong possibility that an environmental concern variable that positively affects risk perception of nuclear power (e.g., concern about environmental safety) may negatively affect nuclear power acceptance by affecting such perception. In this case, if such an environmental concern variable is also associated with GHG/fine dust concerns, there is a possibility that such concern variable is a third variable that can explain the negative relationships between GHG/fine dust concerns and nuclear power acceptance. Therefore, future studies need to include perceptions of nuclear power and their antecedent variables associated with GHG/fine dust concerns.

Third, the present study only focused on environmental motives for generation sources. However, the expansion of new renewable energy accompanying nuclear phase-out has other additional motives: for example, economic benefits (e.g., development of related technology and industries), safety (e.g., liberation from the danger of radioactive leakage and nuclear accidents), and others [77]. Thus, in exploring which of the motives for new renewable energy can be met by nuclear power, researchers must also consider these motives.

Fourth, our dataset did not reflect the respondents' proximity to nuclear facilities in the analysis despite the possibility that individuals living in the vicinity of a nuclear facility may respond differently to environmental issues and nuclear power. This study's survey only distinguished the residential area at the province or metropolitan city levels, which is not detailed enough for precise proximity indication. For example, Uljin County, the location of the Hanul Nuclear Power Site, belongs to Gyeongsangbuk Province but is bordered by Gangwon Province. Thus, several areas in Gangwon Province are closer to this county than many other areas that belong to the county's province. Therefore, future studies need to measure the residential area at the city or county level to get an area's precise proximity to a nuclear facility.

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.

References

[1] IAEA, Nuclear Power Reactors in the World, International Atomic Energy Agency. Available online: https://www.iaea.org/publications/12237/nuclear-power-reactors-in-the-world. (Accessed 25 June 2022).
[2] Q. Li, S. Roh, J.W. Lee, Segmenting the South Korean public according to their preferred direction for electricity mix reform, Sustainability 12 (2020) 9053.
[3] S. Ha, S. Tae, R. Kim, A study on the limitations of South Korea's National Roadmap for Greenhouse Gas Reduction by 2030 and suggestions for improvement, Sustainability 11 (2019) 3969.
[4] A. Maennel, H.-G. Kim, Comparison of greenhouse gas reduction potential through renewable energy transition in South Korea and Germany, Energies 11 (2018) 206.
[5] H. Lee, South Korea looks to nuclear expansion in bid to meet climate targets, Bloomberg, 16 June 2022. Available online: https://www.bloomberg.com/news/articles/2022-06-16/korea-looks-to-nuclear-expansion-in-bid-to-meet-climate-targets. (Accessed 25 June 2022).
[6] J. Chun, Controversies rising: we don't use any more because it's dangerous, but we recommend to you? (written in Korean), Chosun Biz, 21 November 2017. Available online: http://biz.chosun.com/site/data/html_dir/2017/10/24/2017102402034.html. (Accessed 25 June 2022).
[7] J.-B. Chung, Public deliberation on the national nuclear energy policy in Korea—Small successes but bigger challenges, Energy Pol. 145 (2020), 111724.
[8] H. Kim, E.-C. Jeon, Structural changes to nuclear energy industries and the economic effects resulting from energy transition policies in South Korea, Energies 13 (2020) 1806.
[9] E. Lim, South Korea's nuclear dilemmas, Journal for Peace and Nuclear Disarmament 2 (2019) 297–318.
[10] E. Lee, Can nuclear energy power South Korea's future? The Diplomat, 25 June 2022. Available online: https://thediplomat.com/2022/06/can-nuclear-energy-power-south-koreas-future. (Accessed 25 June 2022).
[11] N.C. Bronfman, R.B. Jiménez, P.C. Arévalo, L.A. Cifuentes, Understanding social acceptance of electricity generation sources, Energy Pol. 46 (2012) 246–252.
[12] J.J. Cohen, J. Reichl, M. Schmidthaler, Re-focussing research efforts on the public acceptance of energy infrastructure: a critical review, Energy 76 (2014) 4–9.
[13] E. Im, J.K. Kim, S.M. Woo, Study on the policy literacy of the Republic of Korea regarding nuclear and new-renewable energy, Nucl. Eng. Technol. 54 (2022) 741–748.
[14] MOTIE, The 9th Basic Plan for Long-Term Electricity Supply and Demand (written in Korean), Ministry of Trade Industry and Energy Republic of Korea. Available online: https://www.motie.go.kr/motie/ne/presse/press2/bbs/

bbsView.do?bbs_seq_n=163670&bbs_cd_n=81. (Accessed 25 June 2022).
[15] D. Shindell, C.J. Smith, Climate and air-quality benefits of a realistic phase-out of fossil fuels, Nature 573 (2019) 408–411.
[16] G.-H. Lim, W.-J. Jung, T.-H. Kim, S.-Y.T. Lee, The cognitive and economic value of a nuclear power plant in Korea, Nucl. Eng. Technol. 49 (2017) 609–620.
[17] D. Kang, J.-E. Kim, Fine, ultrafine, and yellow dust: emerging health problems in Korea, J. Kor. Med. Sci. 29 (2014) 621–622.
[18] A. Fifield, Y. Seo, Smog becomes a political issue in South Korean election, The Washington Post, 27 April 2017. Available online: https://www.washingtonpost.com/world/asia_pacific/smog-becomes-a-political-issue-in-south-korean-election/2017/04/27/afd55dba-1a2d-11e7-8598-9a99da559f9e_story.html. (Accessed 25 June 2022).
[19] S. Lee, Korea's new comprehensive plan on fine dust and its implications for policy and research, Research in Brief 29 (2018) 1–7.
[20] M. Park, M. Barrett, T.G. Cassarino, Assessment of future renewable energy scenarios in South Korea based on costs, emissions and weather-driven hourly simulation, Renew. Energy 143 (2019) 1388–1396.
[21] WNA, Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources, World Nuclear Association. Available online: http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf. (Accessed 25 June 2022).
[22] R. Dones, T. Heck, M.F. Emmenegger, N. Jungbluth, Life cycle inventories for the nuclear and natural gas energy systems, and examples of uncertainty analysis, Int. J. Life Cycle Assess. 10 (2005) 10–23.
[23] B. Van der Zwaan, The role of nuclear power in mitigating emissions from electricity generation, Energy Strategy Rev. 1 (2013) 296–301.
[24] T.-S. Chan, Concerns for environmental issues and consumer purchase preferences: a two-country study, J. Int. Consum. Market. 9 (1996) 43–55.
[25] A. Kollmuss, J. Agyeman, Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? Environ. Educ. Res. 8 (2002) 239–260.
[26] I. Ajzen, The theory of planned behavior, Organ. Behav. Hum. Decis. Process. 50 (1991) 179–211.
[27] B. Meng, B.-L. Chua, H.B. Ryu, H. Han, Volunteer tourism (VT) traveler behavior: merging norm activation model and theory of planned behavior, J. Sustain. Tourism 28 (2020) 1947–1969.
[28] J.-B. Chung, E.-S. Kim, Public perception of energy transition in Korea: nuclear power, climate change, and party preference, Energy Pol. 116 (2018) 137–144.
[29] A. Spence, W. Poortinga, N. Pidgeon, I. Lorenzoni, Public perceptions of energy choices: the influence of beliefs about climate change and the environment, Energy Environ. 21 (2010) 385–407.
[30] A. Vainio, R. Paloniemi, V. Varho, Weighing the risks of nuclear energy and climate change: trust in different information sources, perceived risks, and willingness to pay for alternatives to nuclear power, Risk Anal. 37 (2017) 557–569.
[31] B.D. Haig, What is a spurious correlation? Understand. Stat. 2 (2003) 125–132.
[32] A. Ward, Spurious correlations and causal inferences, Erkenntnis 78 (2013) 699–712.
[33] A. Corner, D. Venables, A. Spence, W. Poortinga, C. Demski, N. Pidgeon, Nuclear power, climate change and energy security: exploring British public attitudes, Energy Pol. 39 (2011) 4823–4833.
[34] G. Perlaviciute, L. Steg, The influence of values on evaluations of energy alternatives, Renew. Energy 77 (2015) 259–267.
[35] J.J. Kim, J. Hwang, Merging the norm activation model and the theory of planned behavior in the context of drone food delivery services: does the level of product knowledge really matter? J. Hospit. Tourism Manag. 42 (2020) 1–11.
[36] M.H. Le, P.M. Nguyen, Integrating the theory of planned behavior and the norm activation model to investigate organic food purchase intention: evidence from vietnam, Sustainability 14 (2022) 816.
[37] H. Han, S.S. Hyun, Drivers of customer decision to visit an environmentally responsible museum: merging the theory of planned behavior and norm activation theory, J. Trav. Tourism Market. 34 (2017) 1155–1168.
[38] S. Danish, Ud-Din Khan, A. Ahmad, Testing the pollution haven hypothesis on the pathway of sustainable development: accounting the role of nuclear energy consumption, Nucl. Eng. Technol. 53 (2021) 2746–2752.
[39] X. Hu, W. Zhu, J. Wei, Effects of information strategies on public acceptance of nuclear energy, Energy 231 (2021), 120907.
[40] N.F. Pidgeon, I. Lorenzoni, W. Poortinga, Climate change or nuclear power—No thanks! A quantitative study of public perceptions and risk framing in Britain, Global Environ. Change 18 (2008) 69–85.
[41] P.C. Stern, T. Dietz, The value basis of environmental concern, J. Soc. Issues 50 (1994) 65–84.
[42] P.C. Stern, T. Dietz, T. Abel, G.A. Guagnano, L. Kalof, A value-belief-norm theory of support for social movements: the case of environmentalism, Hum. Ecol. Rev. 6 (1999) 81–97.
[43] P. Stern, Toward a coherent theory of environmentally significant behavior, J. Soc. Issues 56 (2000) 407–424.
[44] A.M. Nordlund, J. Garvill, Effects of values, problem awareness, and personal norm on willingness to reduce personal car use, J. Environ. Psychol. 23 (2003) 339–347.
[45] A.M. Nordlund, J. Garvill, Value structures behind proenvironmental behavior, Environ. Behav. 34 (2002) 740–756.
[46] Y. Zhang, H.-L. Zhang, J. Zhang, S. Cheng, Predicting residents' pro-environmental behaviors at tourist sites: the role of awareness of disaster's consequences, values, and place attachment, J. Environ. Psychol. 40 (2014) 131–146.
[47] A.C. Landon, K.M. Woosnam, B.B. Boley, Modeling the psychological antecedents to tourists' pro-sustainable behaviors: an application of the value-belief-norm model, J. Sustain. Tourism 26 (2018) 957–972.
[48] E.M. Ghazali, B. Nguyen, D.S. Mutum, S.-F. Yap, Pro-environmental behaviours and Value-Belief-Norm theory: assessing unobserved heterogeneity of two ethnic groups, Sustainability 11 (2019) 3237.
[49] S.C. Whitfield, E.A. Rosa, A. Dan, T. Dietz, The future of nuclear power: value orientations and risk perception, Risk Anal. 29 (2009) 425–437.
[50] J.I. De Groot, L. Steg, Morality and nuclear energy: perceptions of risks and benefits, personal norms, and willingness to take action related to nuclear energy, Risk Anal. 30 (2010) 1363–1373.
[51] L. Steg, L. Dreijerink, W. Abrahamse, Factors influencing the acceptability of energy policies: a test of VBN theory, J. Environ. Psychol. 25 (2005) 415–425.
[52] D. Bidwell, The role of values in public beliefs and attitudes towards commercial wind energy, Energy Pol. 58 (2013) 189–199.
[53] D.L. Paulhus, R.W. Robins, K.H. Trzesniewski, J.L. Tracy, Two replicable suppressor situations in personality research, Multivariate Behav. Res. 39 (2004) 303–328.
[54] B. Hidalgo, M. Goodman, Multivariate or multivariable regression? Am. J. Publ. Health 103 (2013) 39–40.
[55] V.H. Visschers, M. Siegrist, Find the differences and the similarities: relating perceived benefits, perceived costs and protected values to acceptance of five energy technologies, J. Environ. Psychol. 40 (2014) 117–130.
[56] R. McNamee, Regression modelling and other methods to control confounding, Occup. Environ. Med. 62 (2005) 500–506.
[57] D.P. MacKinnon, J.L. Krull, C.M. Lockwood, Equivalence of the mediation, confounding and suppression effect, Prev. Sci. 1 (2000) 173–181.
[58] Bloomberg, Hyundai Research Institute, Bloomberg. Available online: https://www.bloomberg.com/profile/company/6647228Z:KS. (Accessed 25 June 2022).
[59] R. Iliyasu, I. Etikan, Comparison of quota sampling and stratified random sampling, Biom. Biostat. Int. J. Rev 10 (2021) 24–27.
[60] J. Wang, S. Kim, Comparative analysis of public attitudes toward nuclear power energy across 27 European countries by applying the multilevel model, Sustainability 10 (2018) 1518.
[61] S. Roh, J.W. Lee, Differentiated influences of benefit and risk perceptions on nuclear power acceptance according to acceptance levels: evidence from Korea, J. Nucl. Sci. Technol. 54 (2017) 830–836.
[62] C.Z. Mooney, R.D. Duval. Bootstrapping: a Nonparametric Approach to Statistical Inference, Sage Publications, Newbury Park, CA, 1993.
[63] W. Ascher, Bringing in the Future, University of Chicago Press, Chicago, 2009, pp. 213–228.
[64] R.J. Lewicki, C. Brinsfield, Framing trust: trust as a heuristic, in: W.A. Donohue, R.G. Rogan, S. Kaufman (Eds.), Framing Matters: Perspectives on Negotiation Research and Practice in Communication, Peter Lang Publishing, New York, 2011, pp. 110–135.
[65] S. Roh, Big data analysis of public acceptance of nuclear power in Korea, Nucl. Eng. Technol. 49 (2017) 850–854.
[66] NEA, Nuclear Energy, Society and Nuclear Energy: Towards a Better Understanding, Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD). Available online: https://www.oecd-nea.org/upload/docs/application/pdf/2020-06/3677-society.pdf. (Accessed 25 June 2022).
[67] Y.-K. Lee, Sustainability of nuclear energy in Korea: from the users' perspective, Energy Pol. 147 (2020), 111761.
[68] V.H.M. Visschers, C. Keller, M. Siegrist, Climate change benefits and energy supply benefits as determinants of acceptance of nuclear power stations: investigating an explanatory model, Energy Pol. 39 (2011) 3621–3629.
[69] K. Bickerstaff, P. Simmons, N. Pidgeon, Constructing responsibilities for risk: negotiating citizen—state relationships, Environ. Plann. 40 (2008) 1312–1330.
[70] L. Peng, Y. Zhang, F. Li, Q. Wang, X. Chen, A. Yu, Policy implication of nuclear energy's potential for energy optimization and CO2 mitigation: a case study of Fujian, China, Nucl. Eng. Technol. 51 (2019) 1154–1162.
[71] L. Cummings, The "trust" heuristic: arguments from authority in public health, Health Commun. 29 (2014) 1043–1056.
[72] S.-J. Yun, Nuclear power for climate mitigation? Contesting frames in Korean newspapers, Asia Eur. J. 10 (2012) 57–73.
[73] T. Kalinowski, The politics of climate change in a neo-developmental state: the case of South Korea, Int. Polit. Sci. Rev. 42 (2020) 48–63.
[74] A.K.S. Ong, Y.T. Prasetyo, J.M.L.D. Salazar, J.J.C. Erfe, A.A. Abella, M.N. Young, et al., Investigating the acceptance of the reopening Bataan nuclear power plant: integrating protection motivation theory and extended theory of planned behavior, Nucl. Eng. Technol. 54 (2022) 1115–1125.
[75] S. Roh, J.W. Lee, Differentiated effects of risk perception dimensions on nuclear power acceptance in South Korea, Energy Pol. 122 (2018) 727–735.
[76] Y. He, Y. Li, D. Xia, T. Zhang, Y. Wang, L. Hu, et al., Moderating effect of regulatory focus on public acceptance of nuclear energy, Nucl. Eng. Technol. 51 (2019) 2034–2041.
[77] S. Roh, D. Kim, Positioning of major energy sources in Korea and its implications, Int. J. Energy Res. 41 (2017) 2421–2429.