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Science Literacy or Value Predisposition? A Meta-Analysis of Factors Predicting Public Perceptions of Benefits, Risks, and Acceptance of Nuclear Energy

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Abstract

Nuclear energy is widely regarded as a controversial technology that polarizes public opinion. Guided by the scientific literacy and cognitive miser models, this study systematically identified and examined the magnitude of the effects of 19 predictors on public perceptions of benefits, risks, and acceptance of nuclear energy. We meta-analysed 34 empirical studies, representing a total sample of 32,938 participants and 129 independent correlations. The findings demonstrated that trust substantially affected public *perception of benefits* regarding nuclear energy. Sex, education, public perception of benefits regarding nuclear energy, trust, and public deliberation substantially influenced public *perception of risks* regarding nuclear energy. Moreover, sex, education, public perceptions of benefits, risks and costs regarding nuclear energy, knowledge, and trust substantially affected public *acceptance* of nuclear energy. Country of sample and time period of data collection moderated public perceptions of benefits, risks, and acceptance of nuclear energy. Implications for future research are discussed.

Keywords

Nuclear energy; meta-analysis; risk perception; benefit perception; science knowledge

Science Literacy or Value Predisposition? A Meta-Analysis of Factors Predicting Public Perceptions of Benefits, Risks, and Acceptance of Nuclear Energy

Global energy demands have increased substantially due to the rapid pace of population growth, economic development, and rising household incomes (He, Mol, Zhang, & Lu, 2014). These energy demands have fuelled many countries to consider nuclear energy as a key energy source. However, nuclear energy has been consistently placed at the forefront of public debate since its inception (Ho, 2017). Nuclear energy advocates have emphasized its benefits as an environmentally friendly and secure energy source which supplies electricity at stable prices (International Atomic Energy Agency, 2014). Conversely, critics have expressed concerns over the devastating effects that could result from nuclear accidents, threats posed by nuclear weapon development and proliferation, substantial operational costs of nuclear power plants, and improper handling of radioactive waste (Li, Fuhrmann, Early, & Vedlitz, 2012).

The polarizing attitudes towards nuclear energy are also apparent in national energy policies across countries. For instance, some Asian countries have pursued nuclear expansion plans ambitiously (He et al., 2014). Contrastingly, parts of Europe and North America have decided to phase out nuclear from their energy mix, preferring to invest in energy efficiency and renewable energy (Mah, Hills, & Tao, 2014). Since public opposition has stalled nuclear plans, partly due to the not-in-my-backyard syndrome (Cale & Kromer, 2015; Venables, Pidgeon, Parkhill, Henwood, & Simmons, 2012), it is important to understand what factors shape public perceptions of benefits, risks, and public acceptance of nuclear energy.

Science communication scholars traditionally relied on the scientific literacy model (SLM) to explain the influence of knowledge on attitudes towards controversial technologies. However, scholars in recent years have increasingly argued that people are “cognitive misers” who put in minimal cognitive effort by relying on mental shortcuts such as value predispositions and other heuristics to act as perceptual filters for them to form opinion. Hence, past studies have shown that science knowledge as well as value predispositions and other heuristics influence public attitudes towards nuclear energy (Brossard & Nisbet, 2007).

Despite extensive research studying the relationship between knowledge and public attitudes towards nuclear energy, findings have been mixed. For instance, Stoutenborough, Sturgess, and Vedlitz (2013) illustrated that people who were more knowledgeable about science are more inclined to hold favourable perceptions of nuclear energy. However, other studies yielded negligible effects (Park & Ohm, 2014; Perko, Adam, & Stassen, 2015). Several studies have also suggested that the public primarily utilize value predispositions and other heuristic cues, which could have stronger impacts on public acceptance of nuclear energy. Past public opinion research on nuclear energy examining factors such as public deliberation (Mah et al., 2014) and demographics (Venables et al., 2012) were also inconclusive. Therefore, the varied findings from these individual studies do not provide a consistent and comprehensive conclusion for these relationships.

To address this limitation, this study utilizes a meta-analytical approach to synthesize and systematically analyse the mixed results from studies conducted over the past two decades. Furthermore, the aggregation of studies will strengthen the statistical power of the findings obtained, allowing us to determine the effect size of the variables. This study also seeks to identify and measure the magnitude of the key determinants of public perceptions of (a) benefits, (b) risks, and (c) acceptance of nuclear energy. Due to the fluctuating public attitudes towards nuclear energy over time (Ansolabehere & Konisky, 2009; Stoutenborough et al., 2013), and across countries, this study also examines the effects of two potential moderators—country and time period of data collection.

Theoretically, the findings of this meta-analysis can clarify and inform the scholarly community about the roles of science knowledge as well as value predispositions and other heuristics towards nuclear energy. Practically, the insights from this study can inform policmakers, communication practitioners, and nuclear experts of effective communication strategies to increase public understanding of governmental decisions.

Theoretical frameworks: SLM vs. cognitive miser model

Science communication scholars are divided over the impacts of the SLM and the cognitive miser model (CMM) in shaping public attitudes. Proponents of the SLM argue that providing scientific information will enhance public support for controversial technologies (Miller, Pardo, & Niwa, 1997; Miller & Kimmel, 2001). Contrastingly, a growing body of recent literature found that value predispositions and other heuristics provide greater predictive power for controversial technologies (Ho, Brossard, & Scheufele, 2008; Ho, Scheufele, & Corley, 2010; Kim, Kim, Krishna, & Kim, 2012). Value predispositions such as trust (Mah et al., 2014) and other heuristics such as benefit perception (Park & Ohm, 2014), risk perception (Pidgeon, Henwood, Parkhill, Venables, & Simmons, 2008), and cost perception (Mah et al., 2014) provide a perceptual filter through which people form opinion about nuclear energy. This supports the CMM, which states that people typically rely on cognitive shortcuts to form opinion about controversial technologies when they have limited time and resources (Scheufele & Lewenstein, 2005). Therefore, this study identifies three main categories of factors to explain public perception of benefits, risks, and acceptance of nuclear energy: (1) science knowledge, (2) value predispositions and other heuristics, as well as (3) socio-demographic factors.

Science knowledge

Knowledge of nuclear energy encompasses both domain-specific and general knowledge. The former pertains to the level of understanding of nuclear energy (Arikawa, Cao, & Matsumoto, 2014; Stoutenborough et al., 2013), while the latter refers to the degree of understanding of the prevailing national energy policies (Chung & Yeung, 2013; He et al., 2014). Scientists typically possess in-depth understanding of nuclear energy. However, the public often only possess general knowledge and receive information mainly from the media, which typically overinflate the risks of nuclear energy (Gardner, 2008).

Extant studies reflect mixed empirical associations between science knowledge and public perceptions of benefits, risks, and acceptance of nuclear energy. Specifically, findings about the direction and strength of association between variables are inconclusive. While some findings illustrate an inverse relationship between knowledge and risk perception (Li et al., 2012; Perko et al., 2015), others depict otherwise (Zhu, Wei, & Zhao, 2016). Additionally, Park and Ohm (2014) found negligible effects of knowledge on both benefit and risk perception. Positive associations between knowledge and acceptance of nuclear energy were also exhibited consistently (Arikawa et al., 2014; Stoutenborough et al., 2013). These findings show divergent strengths of associations and directions between knowledge and attitudes. Thus, a meta-analysis is necessary to tease out the variability in extant literature, and provide conclusions.

Value predisposition and other heuristics

Trust. In the context of nuclear energy, trust in social actors such as the government and relevant authorities is key to shaping public perceptions (Ertör-Akyazı, Adaman, Özkaynak, & Zenginobuz, 2012; Venables et al., 2012). Particularly, trust is enhanced when social actors are perceived to possess the qualities of integrity, transparency, competency, care, fairness, credibility, responsiveness, and reliability (Mah et al., 2014), as well as share similar values with the public (Whitfield, Rosa, Dan, & Dietz, 2009). When individuals lack sufficient knowledge, social trust functions as a cognitive shortcut for opinion formation (Park & Ohm, 2014; Siegrist & Cvetkovich, 2000). In particular, trust was found to reinforce benefit perception of nuclear energy, even in the face of information regarding its hazards (Visschers & Siegrist, 2013). Conversely, trust was inversely related to risk perception

(Bourassa, Doraty, Berdahl, Fried, & Bell, 2016). Trust in governmental management and inspection was also found to substantially influence public acceptance of nuclear energy (Mah et al., 2014).

Benefit perception of nuclear energy. Benefit perception refers to the advantages the public associates with nuclear technology (Ho, 2017). The primary benefits of nuclear energy include energy security (Trousset, Gupta, Jenkins-Smith, Silva, & Herron, 2015), carbon emission reduction and climate change mitigation (de Groot & Steg, 2010), affordable electrical prices, and economic growth (Siegrist, Sutterlin, & Keller, 2014). Past research has identified benefit perception as a key determinant of risk perception (Visschers & Siegrist, 2013), and public acceptance of nuclear energy (Kim, Kim, & Kim, 2014; Park & Ohm, 2014). Similarly, Visschers and Siegrist (2013) demonstrated an inverse relationship between benefit and risk perceptions. Visschers, Keller, and Siegrist (2011) also found that changes in benefit perception regarding nuclear energy before and after the Fukushima nuclear incident significantly influenced public acceptance of nuclear energy. Additionally, benefit perception associated with nuclear energy prevailed over risk perception as a determinant of nuclear energy acceptance (Visschers et al., 2011).

Risk perception of nuclear energy. Risk perception pertains to individuals' beliefs about the severity and probability of the threat occurring, and their ability to remove or cope with it (Hartmann, Apaolaza, D'Souza, Echebarria, & Barrutia, 2013). Technologies such as nuclear energy are deemed as risky when the public feels uncertain about them and perceives them to encroach on nature (Sjöberg, 2002). Risk perception is exacerbated by the potentially debilitating and enduring damage resulting from nuclear accidents and radioactive waste (de Groot & Steg, 2010). Multiple studies found negative associations between risk perception and acceptance of nuclear energy (Ansolabehere & Konisky, 2009; Whitfield et al., 2009). This suggests that those who perceive nuclear energy as safety threats are more likely to oppose it (Pidgeon, Henwood, et al., 2008; Venables et al., 2012).

Cost perception of nuclear energy. Cost perception refers to the perceived types of costs incurred from the adoption and development of nuclear energy. The types of costs perceived to be associated with nuclear energy often include monetary expenses in constructing, operating, and maintaining the nuclear power plants (Park & Ohm, 2014) as well as the price of nuclear-generated electricity (Mah et al., 2014). Park and Ohm (2014) highlighted cost perception as one of the most significant determinants of public attitudes. Based on previous research, lower cost perception was related to increased public acceptance of nuclear energy (Hartmann & Apaolaza, 2007).

Congruent with the CMM, the above-mentioned arguments support the prominent role of value predispositions and other heuristics in influencing public attitudes towards nuclear energy by acting as perceptual filters (Park & Ohm, 2014; Venables et al., 2012). Thus, the evidence underscores a need for a firmer empirical foundation (Allum, Sturgis, Tabourazi, & Brunton-Smith, 2008) to evaluate the roles of the SLM and CMM in explaining the relationship between knowledge, as well as value predispositions and other heuristics with attitudes towards nuclear energy.

Public deliberation

Public deliberation refers to the process where people engage in discourse and weigh the varying perspectives to arrive at a common understanding (Carpini, Cook, & Jacobs, 2004). Conventionally, authorities imposed a top-down approach of governance in policymaking decisions of energy issues (Ertör-Akyazı et al., 2012). However, governments are increasingly adopting public deliberation in the process of developing policies and decision-making to understand public concerns and preferences about energy policies (Rowe & Frewer, 2004). Public deliberation is particularly important for controversial technologies like nuclear energy, as the lack thereof has resulted in public resistance (Ertör-Akyazı et al., 2012). Public deliberation also provides opportunities for participants to undergo elaborative processing about the issue before making final judgements or decisions. For instance, public deliberation was found to be positively related to risk perceptions of nuclear energy (Mah et al., 2014). Therefore, public deliberation facilitates and influences public opinion formation towards nuclear energy.

Socio-demographic factors

Socio-demographic variables examined in the nuclear energy literature typically include sex, age, education, and income (Bourassa et al., 2016; Corner et al., 2011). They have been reported to influence risk perception of nuclear energy (Bourassa et al., 2016; Siegrist et al., 2014). For instance, polarized associations were observed between risk perception of nuclear energy and age. Although Bourassa et al. (2016) found a direct relationship between age and risk perception of nuclear energy, Mah et al. (2014) found the opposite. Additionally, risk perception of nuclear energy was greater among individuals with lower education levels and higher income (Mah et al., 2014).

Studies have also shown that socio-demographic variables affect public acceptance of nuclear energy (Ho et al., 2014; Siegrist et al., 2014). Generally, males indicated greater acceptance and approval of nuclear energy than did females (Arikawa et al., 2014; Siegrist et al., 2014). Differences were also observed across age groups, with older Swiss being less receptive of nuclear energy than their younger counterparts (Siegrist et al., 2014). Furthermore, education and income levels were found to hold positive relations with public acceptance of nuclear energy (Kim et al., 2014).

Research questions

Based on the above-mentioned considerations, we propose the following research questions:

RQ1: To what extent do the following 2 factors—(a) knowledge and (b) trust—predict benefit perception of nuclear energy?

RQ2: To what extent do the following 8 factors—(a) sex, (b) age, (c) education, (d) income, (e) benefit perception, (f) knowledge, (g) trust, and (h) public engagement—predict risk perception of nuclear energy?

RQ3: To what extent do the following 9 factors—(a) sex, (b) age, (c) education, (d) income, (e) risk perception, (f) cost perception, (g) benefit perception, (h) knowledge, and (i) trust—predict public acceptance of nuclear energy?

Method

Retrieval of research studies

The retrieval of studies related to public perceptions of nuclear energy involved multiple procedures. First, we use the keyword: “nuclear” to locate studies in the following online databases, namely PsycINFO, MEDLINE, Communication & Mass Media Complete, EBSCO, Educational Resources Information Center, Web of Science Direct, PubMed, and Nursing & Allied Health Source. Upon amassing relevant publications, we reviewed their references for relevant literature which were not originally included. Alongside the literature search process, the search keywords were developed in an iterative manner to also include: “nuclear energy,” “nuclear power plant(s),” “nuclear power,” and “nuclear plant(s).” Therefore, this systematic and iterative approach ensured that the search keyword development of relevant literature was as comprehensive as possible.

Studies were selected based on the following inclusion and exclusion criteria:

(1) The article should focus on the factors influencing public attitudes and behaviours towards nuclear energy.

(2) To attain a precise estimation of public attitudes and behaviours towards nuclear energy, studies were only included if the quantitative information could be computed or converted into effect size estimates. The statistics presented in the article which were

essential for the calculation of effect sizes included sample sizes, means, correlations, odds ratios, and standardized regression coefficient (β). In addition, a deterministic imputation formula ($r = \beta + .05\lambda$, where λ is 1 if β is non-negative and 0 if β is negative) was utilized in this meta-analysis when the standardized regression coefficient was reported without any additional data to compute an effect size, and when the authors were unable to provide the necessary statistics. This imputation formula was employed in the meta-analysis to transform β's into predicted *r*'s. Despite its potential drawbacks, this deterministic imputation formula remains a superior approach than replacing the missing correlations with zero or the mean of all the correlations (Peterson & Brown, 2005).

(3) Correlations that were examined in only one study were excluded from data analysis. Thus, only correlations that occur in a minimum of two studies were included.

(4) If the article contained two or more data sets, it would be considered as two or more studies.

After perusing the abstracts of the 1232 studies identified in the initial search process, only 132 articles examined public perceptions towards nuclear energy. In addition, 32 of the 132 articles presented quantitative data required for calculating effect sizes, with 2 of the abovementioned studies using 2 datasets. In order to prevent over-representation of particular data sets, the time period and location of data collection were examined to ensure that the data sets did not overlap. After this filtering process, the final sample yielded 34 studies, which represented a total sample of 32,938 participants and produced 129 independent correlations.

Coding procedures

Two coders were trained based on the afore-mentioned coding criteria. To ensure inter-coder reliability, the coders practiced coding and established procedures for resolving inconsistencies and ambiguities. Subsequently, they individually coded the specific study characteristics, predictors, moderators, and statistical indexes in the 34 selected studies. The inter-rater agreement (Cohen's κ) obtained ranged from 0.80 to 1.00, with the average κ = 0.86.

Calculation of effect sizes

Statistics with comparable formats obtained from each study were utilized in the computation of effect sizes. The data formats primarily consisting of correlations, odds ratios, and means with standard deviations were input into the Comprehensive Meta-Analysis 3.0 software. The data were then converted into a homogeneous form of Pearson product-moment correlation (Pearson's *r*). As denoted by Cohen's guidelines of effect size, a small effect size is indicated by a Pearson's *r* of .10–.23; a medium effect size by a Pearson's *r* of .24–.36; and a large effect size by a Pearson's *r* of .37 and above. The total effect sizes of each moderator and dependent variable (public perceptions of benefits, risks, and acceptance of nuclear energy) were obtained by averaging the Pearson's *r* across the selected studies. Each observed correlation from the selected articles was also weighted according to the study's sample size and standard error (Hedges & Olkinm, 1985). Both the Q and I^2 statistics were utilized for the homogeneity test for a comprehensive and rigorous data analytical approach. The random effects model was also administered as most of the Q statistics derived were significant (Hedges & Vevea, 1998).

Results

The data analysis included a summary description for the 34 selected studies, the weighted average of effect sizes from the selected articles, and the moderator analyses.

Weighted correlations

Benefit perception of nuclear energy. Weighted correlations between predictors of benefit perception regarding nuclear energy are presented in Table 1. The findings indicate that trust was positively associated with benefit perception of nuclear energy and yielded a large effect size (r = .52, p < .05). The effect sizes obtained were significantly distinguished from zero at the 95% confidence interval since it did not cross zero. However, knowledge was not a significant predictor since it passed the zero-mark at the 95% confidence intervals.

[Insert Table 1 about here]

Risk perception of nuclear energy. Weighted correlations between the predictors and risk perception regarding nuclear energy are reflected in Table 2. For risk perception of nuclear energy, the predictive power of sex (r = .26, p < .05) was stronger than public deliberation (r = .23, p < .05). According to Cohen's (1988, 1992) guidelines, the effect sizes observed were medium and small, respectively. The weighted effect sizes for both predictors were significantly distinguished from zero since their confidence levels did not cross zero at the 95% confidence interval. Contrastingly, benefit perception was found to be the strongest negative predictor of risk perception towards nuclear energy with a large effect size (r = −.52, p < .05). Furthermore, trust (r = −.25, p < .05) and education (r = −.09, p < .05) demonstrated weak negative associations with risk perception of nuclear energy. The effect size observed for trust was medium.

[Insert Table 2 about here]

In summary, sex, education, benefit perception, trust, and public deliberation were significant predictors of risk perception associated with nuclear energy, while age, income, and knowledge were not significant predictors.

Public acceptance of nuclear energy. Weighted correlations between the predictors and public acceptance of nuclear energy are shown in Table 3. The strongest positive predictor of public acceptance was benefit perception (r = .48, p < .05), which yielded a large effect size. Additionally, sex (r = .23, p < .05) and trust (r = .13, p < .05) demonstrated positive associations with public acceptance of nuclear energy and yielded a small effect size.

Conversely, the strongest negative predictor was cost perception of nuclear energy ($r = -.45$, $p < .05$) which obtained a large effect size. Furthermore, the public's risk perception regarding nuclear energy ($r = -.16$, $p < .05$) and knowledge ($r = -.16$, $p < .05$) were also negatively associated with public acceptance of nuclear energy and obtained a small effect size.

[Insert Table 3 about here]

In summary, sex, knowledge, trust as well as benefit and risk perceptions regarding nuclear energy were significant predictors of public acceptance for nuclear energy since they did not cross zero with 95% confidence intervals. Age and income were not significant predictors since they had crossed the zero-mark at the 95% confidence interval.

Moderator analyses

Significant Q statistics were observed across the chosen articles to indicate a significant heterogeneity of effect sizes among the studies. Such heterogeneous effect sizes across the studies merit subsequent moderator analyses (see Cook, Williams, Guerra, Kim, & Sadek, 2010; Rosenthal, 1991). Specifically, we identified country of sample and time period of data collection as potential moderators of all the factors with heterogeneous effect sizes across the selected articles, including nuclear energy in general. This is also consistent with the fact that the studies included in this meta-analysis examined similar variables but tested them from different geographical contexts and time-periods. Based on the findings from extant literature, these factors were chosen for the moderator analyses.

Among the 34 studies, majority employed samples from North America and Europe: 10 (29.41%) studies used samples from North America including the United States and Canada, while 14 (41.18%) articles were from European countries, including the United Kingdom, Spain, Italy, Switzerland, and Turkey. The remaining 10 studies (29.41%) employed samples from East Asia including Japan, South Korea, China, and Taiwan. Of the

34 studies, 17 were collected before the Fukushima nuclear accident in March 2011, while the other 17 were collected after the accident.

First, the country of sample was established as a promising factor based on prevailing cross-cultural disparities in past studies (Hinman, Rosa, Kleinhesselink, & Lowinger, 1993; Skea, Lechtenböhmer, & Asuka, 2013). These disparities were exemplified in the varying levels of scientific literacy and nuclear dependency across countries, resulting in differing attitudes and behaviours towards nuclear energy. According to the SLM (Laugksch, 2000), higher degree of science knowledge correlates positively with support for new technologies. East Asians were deemed to possess higher scientific literacy and postulated to possess greater public support for nuclear energy than North Americans and Europeans due to their higher scores for Math and Science in the Programme for International Student Assessment (Coughlan, 2015).

Additionally, the time period of data collection (before and after Fukushima) was also chosen as a moderator due to fluctuations in public opinion towards nuclear energy—particularly, after a nuclear accident. Past incidents showed that despite a sharp drop in public support directly after a nuclear accident, this tends to revert back to initial levels over time (Wallard, Duffy, & Cornick, 2012; Newport, 2012). For instance, public support towards nuclear energy in the United States decreased between mid-1970s and early 2000s due to the Three Mile Island and Chernobyl incidents (Siegrist & Visschers, 2013), but recent Gallup polls indicated otherwise (Carroll, 2006; Newport, 2011). Therefore, the time period of data collection proved to evoke varying levels of public support for nuclear energy.

According to the moderator analyses presented in Table 4, the country of sample significantly moderated the relationship between trust and benefit perception ($QB = 3.04$, $p < .05$), trust and risk perception ($QB = 18.33$, $p < .001$), as well as trust and acceptance of nuclear energy ($QB = 5.62$, $p < .001$). The effect of trust on benefit perception was also stronger in Europe than East Asia, while the effect observed for trust on risk perception was greater in Europe than East Asia and North America. However, effects on public acceptance of nuclear energy were found to be stronger in East Asia than Europe and North America.

The moderator analyses for time are shown in Table 5. Based on the findings, the time period of data collection significantly moderated the relationship between public acceptance and benefit perception of nuclear energy ($QB = 5.55$, $p < .001$). Furthermore, it also significantly moderated the association of public acceptance and trust ($QB = 5.27$, $p < .001$). The effects observed for benefit perception of nuclear energy and trust on public acceptance were stronger after the Fukushima nuclear accident.

[Insert Tables 4 and 5 here]

Discussion

This study synthesized findings obtained from past studies to provide a comprehensive overview of the main factors underlying benefit perception, risk perception, and acceptance of nuclear energy. The results show that public perceptions of benefits, risks, and acceptance of nuclear energy are primarily impacted by value predispositions and other heuristics rather than science knowledge. The marginal role of science knowledge in shaping public attitudes towards nuclear energy has also been reflected in public opinion studies of science and technology in general (Allum et al., 2008). Therefore, the findings indicate a limited predictive and explanatory power of the SLM in explaining public attitudes towards nuclear energy. Instead, this meta-analysis highlights the crucial role of the CMM in predicting public attitudes towards nuclear energy.

Predictors of benefit perception

Trust displayed a strong positive relationship with benefit perception of nuclear energy, while the association between science knowledge with benefit perception were non-significant. These findings demonstrate that people evaluate the benefits of nuclear energy using their value predispositions and other heuristics when they lack sufficient knowledge (Visschers et al., 2011; Visschers & Siegrist, 2013), which supports the CMM. In particular, people trusted authorities perceived to be reliable, understanding (Park & Ohm, 2014), and shared similar values (Bourassa et al., 2016).

Predictors of risk perception

Benefit perception, sex, and social trust related strongly to risk perception. However, science knowledge was not a significant predictor of risk perception towards nuclear energy. Females perceived greater risks regarding nuclear energy than males. This difference based on sex could be attributed to the varying mental associations with nuclear energy. As mentioned in Keller, Visschers, and Siegrist (2012), females generally associated nuclear energy with undesirable concepts such as “accident” and “military use.” Conversely, males associated nuclear energy with positive descriptors including “hope,” “benefit,” and “technological advancement” (Keller et al., 2012). Thus, the differences in conceptual understanding and affective associations towards nuclear energy could have polarized risk perception of nuclear energy between sexes.

Meanwhile, social trust was negatively associated with risk perception. Specifically, risk perception increased when people mistrusted the government’s credibility, competency to safeguard their welfare, and transparency of nuclear operators (Mah et al., 2014). Therefore, the findings demonstrated the importance of value predispositions such as trust and other heuristics in effectively managing and reducing risk perceptions of nuclear energy.

Risk perceptions rose alongside public deliberation, demonstrating that the mere provision of public deliberation does not guarantee increased receptiveness towards nuclear energy (Mah et al., 2014). Instead, ineffective public deliberation may foster social distrust (Involve and GuideStar UK, 2008). Multiple barriers, such as time constraints, limited public awareness, pre-existing distrust towards relevant authorities, and limited access to information, could also potentially obstruct the effectiveness of public deliberation. Therefore, these findings highlight the importance of implementing and facilitating effective public deliberation to understand public attitudes and enhance social trust to increase public support for governmental decisions.

Predictors of public acceptance for nuclear energy

Public acceptance of nuclear energy was found to be primarily influenced by benefit and cost perceptions. In comparison, science knowledge, sex, perceived risks, and trust had a smaller impact on public acceptance of nuclear energy. These findings indicate that knowledge had a marginal impact on public attitudes towards nuclear energy, while highlighting the differential effects of various value predispositions and other heuristics. This suggests that media frames to increase public acceptance of nuclear energy should provide greater emphasis on the benefits associated with nuclear energy, and address how monetary and environmental costs can be offset.

Varied measures of knowledge. Contrary to the SLM, science knowledge and public acceptance of nuclear energy were negatively related. This could be explained by the varied definitions and measures of science knowledge across the studies included in this meta-analysis. For instance, Showers and Shrigley (1995) specifically measured participants' domain-specific knowledge towards nuclear energy, while majority of the studies measured general science knowledge. This could be problematic as individuals with high scientific literacy may lack nuclear-specific knowledge. Hence, the measure of general science knowledge may lack validity in elucidating the relationship between knowledge and attitudes in the context of nuclear energy. These findings suggest that future studies should assess both general scientific knowledge and nuclear-specific knowledge.

Moderator analyses

The moderation analyses revealed that country of sample significantly moderated trust with benefit perception, risk perception, and acceptance of nuclear energy. The larger effect sizes for perceived benefits and risks observed in Europe as compared to East Asia could be attributed to cross-cultural disparities (Hinman et al., 1993; Skea et al., 2013). Culture is a broad concept that encompasses many sub-components such as the customs, beliefs, and social behaviour of a particular society. Hence, a cross-national comparison would provide a better representation of the unique cultures in each country, as well as the shared cultural understandings in a particular region. Therefore, the variance in cultural distance and trust in authorities may partially explain the cross-cultural disparities in the findings.

For instance, collectivistic and individualistic cultures differ in terms of their communication styles as well as value predispositions and other heuristics, which may influence public attitudes towards nuclear energy. In addition, in countries where citizens possess high trust in the competency and ability of authorities to safeguard the welfare of citizens, there will be more support of governmental decisions in adopting nuclear energy. Conversely, in countries where citizens possess distrust in their authorities, there may be public opposition and obstruction to the government's decisions to adopt and develop nuclear energy. Therefore, these components of culture may account for the cross-national variances in public attitudes towards nuclear energy.

Time also significantly moderated public acceptance of nuclear energy with benefit perception and trust. After the Fukushima nuclear accident, both the correlations between benefit perception and support, as well as between trust and public acceptance of nuclear energy were strengthened. The Fukushima nuclear accident could have highlighted the salience of nuclear energy with increased media coverage, public interest, and debate. Subsequently, people increasingly utilized their value predisposition and other heuristics as perceptual filters in attitude-formation towards nuclear energy. In other words, people relied more on their trust in authorities, and scrutinized the benefits of nuclear energy in deciding whether they would accept nuclear energy.

Study limitations

Several effect sizes were calculated based on two studies, due to the lack of relevant empirical studies. As such, this may limit the accuracy of the "true" average effect size of the relationships between these variables. To circumvent the limitations and evaluate the accuracy of the average effect sizes, the findings from other meta-analysis studies examining public perceptions towards controversial technologies, or science and technology in general, could be utilized as a guide. This problem could also be mitigated in the future if more research about the variables of interests are conducted.

Theoretical and practical implications

The findings of this meta-analysis provide several noteworthy theoretical and practical implications. Theoretically, the findings showed that public perceptions of benefits, risks, and acceptance of nuclear energy were primarily shaped by value predispositions and other heuristics. In comparison, science knowledge had a smaller influence on public attitudes towards nuclear energy. Overall, the findings indicate that the SLM alone was insufficient to account for the effects observed. This underscores the importance of the CMM in shaping public attitudes towards nuclear energy. Therefore, our findings contribute to the increasing voices of the scholarly community to focus on how individuals' values and beliefs influence opinion formation about science and technologies (Ho et al., 2008; Kim et al., 2012), they also point to several important practical implications regarding public communication of nuclear energy.

Media framing. Key stakeholders should be aware that simply providing information regarding nuclear energy may not be the optimal way to facilitate public understanding. The form of a message is just as important as the content of the message. Numerous scholars have advocated the strategic use of media framing to convey messages about controversial science and emerging technologies (Nisbet & Scheufele, 2007, 2009). The tailoring of media messages that appeal to the value predispositions and other heuristics (e.g. benefit perception) can activate participation from an otherwise inattentive public (Nisbet & Scheufele, 2007, 2009). Different frames or presentation applied to the same content have been shown to result in different outcomes. Pidgeon, Lorenzoni, and Poortinga (2008) showed that framing nuclear energy in terms of energy security instead of climate change mitigation had a larger impact on public acceptance of nuclear technology.

Based on the demographic differences obtained in the findings, communication practitioners, and policymakers could utilize audience segmentation, and tailor media messages accordingly. For instance, females demonstrated greater risk aversion and lower public acceptance towards nuclear energy. Thus, communication campaigns aiming to bolster public acceptance could specifically target social media channels that are frequented by females such as Instagram and Pinterest.

Public deliberation. This meta-analysis demonstrated that the mere provision of public deliberation does not guarantee public acceptance for energy policies. As such, it is important for policymakers to implement effective public deliberation initiatives and refrain from using it as a means to validate finalized decisions (Mah et al., 2014). Upon receiving the suggestions and feedback from public deliberation initiatives, policymakers should implement and consistently revise legislations. This would uphold operational transparency and open communication between policymakers and publics to foster and enhance social trust (Ho et al., 2010; Park & Ohm, 2014). Therefore, policymakers could utilize the findings in this study to implement effective public deliberation, and utilize these initiatives to build rapport and strengthen social trust.

Conclusion and directions for future research

Our meta-analysis highlighted several research gaps to be investigated in future studies. First, most extant studies were based on offline opinion expression and self-reported data from experiments or surveys. Given the diverse views and user interactivity on online platforms, it would be interesting to look at opinion expression in forums and social media. The lack of identifiability on such platforms may encourage expression of alternative views and reduce social stigmas prevalent offline (Ho & McLeod, 2008; Joinson, 2001). Additionally, perceived homophily in online discussions could shape perceptions towards nuclear energy (Ma, Krishnan, & Montgomery, 2015).

Second, most of the selected studies were conducted in Europe, North America, and East Asian countries. Limited studies have been conducted in South America, Australia, Africa, South Asia, Southeast Asia, and the Middle East. The cross-cultural disparities in these regions could provide differing perceptions regarding benefit, risk, and acceptance of nuclear energy from their respective geographical and cultural standpoints. Moreover, the variations in technological development and nuclear expertise across countries also present an interesting research area. Future studies could compare public perceptions of nuclear energy across countries with varying levels of nuclear dependency, as determined by the number of operable nuclear reactors and their nationwide nuclear electricity generation.

As environmental sustainability becomes increasingly integrated into national developmental plans, more countries have started harnessing renewable energy to generate electricity. Thus, future research could also compare public attitudes towards various types of renewable energies with nuclear energy. Finally, future studies can also consider examining public deliberation as the outcome variable to determine the optimal approach to facilitate public deliberation.

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Appendix

Table 1.
Weighted correlations: benefit perception of nuclear energy as outcome variable.

					95% CI			
DV	IV	*k*	*N*	Effect size	Low	High	*Q*	*I²*
Benefit Perception	Knowledge	2	2973	-.01	-.05	.03	1%	1%
	Trust	5	1647	.52	.74	.19	99%***	99%

Notes: *k* = number of studies; *N* = total sample size for all studies combined; effect size is Pearson's *r;* 95% CI= lower and upper limits of 95% confidence interval for effect size*; Q*, *I²* = Cochran's (1954) measure of homogeneity.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Table 2.
Weighted correlations: risk perception of nuclear energy as outcome variable.

					95% CI			
DV	IV	*k*	*N*	Effect size	Low	High	*Q*	*I²*
	Sex (Male)	7	7367	.26	.07	.43	98%***	98%
Risk Perception	Age	7	7385	.01	-.02	.04	39%	39%
	Education	5	3655	-.09	-.18	-.01	84%***	84%
	Income	3	1888	.06	-.10	.22	91%***	91%
	Benefit perception	2	1580	-.52	-60	-.44	9%	9%
	Knowledge	7	1580	-.04	-.10	.01	71%***	71%
	Trust	8	4761	-.25	-.37	-.13	97%***	97%
	Public deliberation	2	1306	.23	.13	.32	69%	69%

Notes: *k* = number of studies; *N* = total sample size for all studies combined; effect size is Pearson's *r;* 95% CI= lower and upper limits of 95% confidence interval for effect size; *Q*, *I²* = Cochran's (1954) measure of homogeneity.
*$p < .05$.
**$p < .01$.
***$p < .001$.

Table 3.
Weighted correlations: public acceptance of nuclear energy as outcome variable.

DV	IV	*k*	*N*	Effect Size	95% CI Low	95% CI High	*Q*	I^2
	Sex (Male)	13	16,573	.23	.13	.33	97%***	97%
Acceptance	Age	11	12,291	-.02	-.08	.02	96%***	96%
	Education	6	6106	-.04	-.06	-.01	1%	1%
	Income	3	4661	-.01	-.04	.02	1%	1%
	Risk perception	16	17,673	-.16	-.27	-.09	95%***	95%
	Cost perception	4	4489	-.45	.76	.03	99%***	99%
	Benefit perception	7	8113	.48	.05	.72	99%***	99%
	Knowledge	6	6609	-.16	-.30	-.02	96%***	96%
	Trust	9	13,795	.13	.08	.18	88%***	88%

Notes: *k* = number of studies; *N* = total sample size for all studies combined; effect size is Pearson's *r;* 95% CI= lower and upper limits of 95% confidence interval for effect size; *Q*, I^2 = Cochran's (1954) measure of homogeneity.
**p* < .05.
***p* < .01.
****p* < .001.

Table 4.
Moderator analysis: country.

DV	IV	Country	*k*	Effect size	95% CI Low	95% CI High	*Q*	I^2
Benefit Perception	Trust	Asia	2	.24	.16	.32	67%*	67%
		Europe	3	.67	.18	.88		
Risk Perception	Trust	Asia	3	-.18	-.26	-.11	89%***	89%
		Europe	3	-.47	-.58	-.36		
		North America	2	-.21	-.26	-.17		
Acceptance	Trust	Asia	3	.20	.13	.27	98%***	98%
		Europe	3	.10	.04	.16		
		North America	3	.10	.02	.17		

Notes: *k* = number of studies; *N* = total sample size for all studies combined; effect size is Pearson's *r;* 95% CI= lower and upper limits of 95% confidence interval for effect size; *Q*, I^2 = Cochran's (1954) measure of homogeneity.
**p* < .05.
***p* < .01.
****p* < .001.

Table 5.
Moderator analysis: time.

DV	IV	Time	*k*	Effect size	95% CI Low	95% CI High	*Q*	I^2
Acceptance	Benefit perception	Before Fukushima	5	.34	-.01	.67	82%***	82%
		After Fukushima	2	.73	.64	.81		
Acceptance	Trust	Before Fukushima	5	.09	.04	.14	81%***	81%
		After Fukushima	4	.18	.12	.24		

Notes: *k* = number of studies*;* *N* = total sample size for all studies combined; effect size is Pearson's *r;* 95% CI= lower and upper limits of 95% confidence interval for effect size; *Q*, I^2 = Cochran's (1954) measure of homogeneity.
*$p < .05$.
**$p < .01$.
***$p < .001$.