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A Zero-Carbon Nuclear Energy Future? Lessons Learned from Perceptions of Climate Change and Nuclear Waste

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Abstract: Nuclear energy is proposed as part of the solution to a net-zero carbon future. However, environmental issues with nuclear energy remain. In this study, a total of 1616 participants from across the U.S. stated their position on the following statements: "Nuclear energy is a clean energy source", "Nuclear energy may be part of the solution to climate change", "I am willing to accept the building of new nuclear power stations if it is environmentally friendly and had a zero-carbon footprint", and "Nuclear power may lead to more pollution and environmental contamination". Participants were also asked "Do you think nuclear energy is a zero-carbon energy?" Logistic regression was used to determine how concern around climate change and nuclear waste predicted participant responses. Latent class analysis (LCA) was used to determine segments of respondents based on their perceptions of nuclear energy and the environment. Nuclear energy was perceived as being zero-carbon (74% agree), but not necessarily clean (50% agree). Nuclear energy was perceived as part of the solution to climate change (51% agree), but concern around more pollution and environmental contamination remained (42% agree). Concern around climate change was associated with greater odds of acceptance of nuclear energy, while concern around nuclear waste was associated with the opposite. The LCA suggested a "favorable", "neutral", and "negative" class, for which approximately 40%, 52%, and 8% of participants, respectively, belonged. This study suggests conditional (or reluctant) support for nuclear energy is occurring.

Keywords: nuclear energy; climate change; nuclear waste; perceptions; zero-carbon

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1. Introduction

Stakeholders and interest groups create "policy images" around social, environmental, or political issues, and these images largely define whether an issue has support or opposition. Baumgartner, Jones, and Mortensen for instance, use policy images to describe their Punctuated Equilibrium Theory (PET) of the public policy process [1]. According to one of the original articulations of PET by Baumgartner and Jones, a policy image is an effort by various groups to define how an issue is perceived by the public. [2]. According to these scholars, when a policy issue has a singular positive image, the issue will be more widely supported resulting in a policy monopoly and statis. However, when a negative image of an issue is promoted, groups opposing the policy will be attracted to the policy arena, and these new groups will use multiple political venues (different levels of government, courts, legislative branch, executive branch) to oppose and wrest away power from those who support the issue.

Nuclear energy is one issue that Baumgartner and Jones used to develop PET and to explore the power of policy images and how policy changes [3]. This discussion is currently relevant as nuclear energy is being touted as a part of the energy mix for a low carbon energy future, and the solution is often presented as a risk tradeoff [4] For nuclear energy

to be widely accepted as a part of the energy mix, regaining the support and popularity it had from the late 1940s to the early 1960s, it will have to create a positive policy image which will attract groups formerly neutral or opposed to nuclear energy. There is recent research that shows some potential changes among politically liberal individuals who were found to not necessarily oppose nuclear energy [5]. On the other hand, another study [6] has shown support among individuals living close to a nuclear energy facility, but still found lasting concerns about nuclear energy among individuals living farther away from a nuclear facility. Participants demographics are also associated with perceptions of nuclear energy. For instance, males tend to be more positive than females, and the emotional response to nuclear energy has been found to be more positive among people who are non-Hispanic White, compared to people who are Hispanic [6]. Furthermore, changing perceptions about nuclear energy (or any policy topic) is increasingly difficult in a political world dominated by polarization based not on policy disagreement but instead based on political identity [7] and where individuals increasingly make decisions about scientific issues, not based on fact, but instead based on the individual's political identity [8]. In such a situation, scientists often fall into the "science deficit model" [9] of communication, thinking that more factual information will convince others of the efficacy of a policy, but increasingly, more scientific information does not change individuals' views of policy issues.

The production of nuclear energy remains a salient and often controversial topic in public policy discussions [10]. The electricity generation by commercial nuclear plants, originating in 1958 [11] has been promoted as a carbon-free energy source in a time when the world faces a climate change crisis caused by high carbon emissions from reliance on coal, oil, and natural gas. In 2021, in the US, approximately 19% of the country's energy production comes from nuclear energy [12] with calls to expand nuclear energy coming even from some environmental groups [13]. Critics contend, however, that nuclear energy's role in climate change mitigation would be minimal because of limited uranium fuel source, long construction timelines, technical obstacles, and other costs [14]. In addition, nuclear energy continues to have environmental justice advocates criticize the safety of nuclear plants, problems with the disposal of high-level nuclear waste, the high costs of nuclear energy, potential risks of nuclear weapons production, and the impacts of uranium mining and enrichment on the environment [15]. Other environmental issues, such as the carbon footprint of nuclear power plants, also exist.

In this study, we are interested in exploring how concern regarding climate change and nuclear waste is associated with the perception of nuclear energy. Our empirical study will help provide data on whether the image of nuclear energy among those who are concerned with the environment (as measured by concern about climate change and nuclear waste) is positive or negative. If the perceptions toward nuclear energy are positive among the climate change-concerned, there would be evidence that nuclear energy might grow in popularity and acceptance as groups promote it as a solution to reduce carbon emissions. However, if perceptions towards nuclear energy are negative among participants who are concerned about climate change, it would provide evidence that the impact on climate due to carbon emissions which can be mitigated by nuclear energy has not changed the image of nuclear energy among those environmentally concerned. Furthermore, evidence of individual concerns about nuclear waste helps provide a larger understanding of overall individual perceptions of nuclear energy. Before we explore this question, we first provide some background on the political history of nuclear energy among environmentalists.

2. Nuclear Energy and Environmentalism

After World War II, the policy image of nuclear energy was positive and framed as a national security issue [3]. Beginning in the 1960s, public perceptions about nuclear energy became increasingly negative, and public support declined [3,16]. Specifically, in a twenty-year period from 1945 to 1965, nuclear energy found itself supported by an influential nuclear energy policy community. This community included the Atomic

Energy Commission and the Joint Committee on Atomic Energy, national laboratories, and scientists and engineers in universities. This community had no organized opposition and thus enjoyed widespread public support [16]. In the period from 1945 to 1965, the nuclear energy policy community operated with minimal negative pressure from groups outside of the policy community. Instead, there were several U.S. Congressional acts which helped to promote nuclear energy [3,16].

The political power of the nuclear energy policy community started to fade in the mid-1960s. During this time, nuclear energy found its first organized opposition and some nuclear accidents [17] started to concern the newfound environmental movement. As Duffy [16] argues, nuclear energy was redefined from something essential to national security to an issue that had to be considered in the context of larger debates about environmental protection and public health. This redefinition meant that for the first time, nuclear energy had organized opponents who worked to promote a negative image of nuclear energy and its perceived impacts on the environment. Duffy explains in this regard that nuclear energy was thus wrapped up in larger debates about the role of citizens, the role of government regulation, and the purposes of democracy [16]. This redefinition of the issue and the creation of a negative image attracted additional groups into the nuclear energy policy arena, with the new groups viewing nuclear energy as a threat to the environment and, thus, as a threat to public safety and health. The growth of the environmental movement, growing support for government regulation, and citizen participation all impacted how US society viewed nuclear energy; environmentalism was at the forefront of this movement. Concerns over nuclear contamination, accidents, and nuclear waste put the nuclear energy policy community in opposition to the environmental policy community.

Furthermore, the National Environmental Policy Act (NEPA) in 1970 mandated environmental impact statements to outline the effect a proposed project will have on the environment. These statements brought additional groups (including the courts) into the nuclear energy political arena [3]. While many assert that the meltdown of a nuclear reactor at Three Mile Island (Pennsylvania) in 1979 led to a newfound negative image of nuclear energy, Baumgartner and Jones contend that the image had already changed to a primarily negative one, and that the nuclear energy policy monopoly had begun to erode well before 1979.

In the U.S., Al Gore's 2006 documentary film, "An Inconvenient Truth" is largely credited with bringing the first large-scale public attention to climate change. Additionally, with increased attention to climate change and wars in Afghanistan and Iraq impacted oil supplies, there were significant calls in the U.S. to reduce reliance on fossil fuels. Nuclear energy became considered as a carbon-free energy source. However, making nuclear energy attractive to those concerned about climate change is not an easy task. Since the 1970s, individuals who are concerned with the environment have had negative attitudes towards nuclear energy [18–20], and that perception has remained strong at least up to 12 years ago [21], well past the Gore documentary. The Fukushima nuclear power plant disaster in 2011 further eroded hope for a more positive policy image of nuclear energy [22]. Some of the environmental concerns about nuclear energy include perceptions of environmental harm from a lack of updated nuclear waste disposal methods [23] and concern over the safety of nuclear energy facilities [24]. A study in Finland found an association between an individual's increased perceived risk of nuclear energy and their negative perception of nuclear energy as a way to mitigate climate change [25]. This is consistent with Corner, et al. [26] and their study in Great Britain, which showed that individuals who were more concerned about climate change and had higher environmental values were less likely to support nuclear energy. Pidgeon et al. [27] in their study of Great Britain found only "reluctant acceptance" of nuclear energy when it was presented as a risk–risk tradeoff, and the majority of citizens were dubious of nuclear energy when compared with other alternative energy sources. This finding is reinforced in Bickerstaff et al. [28]. Corner et al. [26] showed that individuals who disliked nuclear energy would give it conditional support if it were a possible solution to climate change. The authors conclude that nuclear

energy has some conditional support when paired as a climate change mitigation feature, particularly if other options are exhausted [26]. Finally, some acceptance of nuclear energy by those who accept human-caused climate change might be tempered by concerns over the safe storage of nuclear waste [27,28]. This means that, while climate change advocates might support nuclear energy as a potential energy source, concerns over where to safely store the waste could outweigh their support of nuclear energy as a potentially climate-friendly energy source. Indeed, there is no long-term storage facility for spent fuel and high-level nuclear waste.

3. The Science and Policy of Carbon Emissions

Increases in global temperatures threaten all living creatures. There is a high correlation between a rise in Earth's overall temperature and the increase in human-produced carbon dioxide emissions [29–33]. Much of these carbon emissions occur during the production of energy, and it is estimated that around 40% of carbon emissions are a result of burning fossil fuels such as coal, oil, and gas [34]. In 2019, fossil fuels accounted for between 80 to 84% of the world's energy consumption [35–37].

The United Nations has instituted International Sustainable Development Goals (SDG) targeting the reduction in human-caused carbon emissions. Further, in response to concerns over human-caused carbon emissions, in January 2019, the United States implemented a new goal of net-zero carbon emissions by 2050 [36], as articulated in the Congressional Climate Crisis Action Plan. This plan also indicates that nuclear energy will be a critical component of the U.S.'s carbon-neutral energy future along with wind, solar, and hydropower [38].

4. Idaho National Laboratory

Idaho does not align with the national 2050 goal and does not have its own renewable target goals such as transitioning to 100% renewable energy sources or becoming zero-carbon emitting by a certain year [39], although in 2021, Idaho state generated 74% of its power from renewable resources [40].

Idaho is home to the U.S. Department of Energy's nuclear energy research center, Idaho National Laboratory (INL). However, nuclear energy is not included in the state's energy mix [29]. The main source of electricity generated within Idaho is hydropower, although chronic drought and increased generation of other renewable energy sources such as wind and solar has caused this to decreased in recent years. Natural gas and wind power make up half of the state's total energy generation [29]. Idaho also relies heavily on the import of petroleum, coal, and some natural gas as the state has minimal fossil fuel reserves. Even with high-producing renewable energy sources, most of Idaho's energy consumption comes from energy generated out of state (about 70% according to a 2019 report by the EIA) [29].

According to the National Conference of State Legislatures, as of 2021, Idaho does not have state-wide Renewable Portfolio Standards (RPS) requiring that renewable energy sources, such as hydropower, solar, or wind, make up a determined percentage of state-produced and commercial electricity [39]. Idaho also does not currently align with the Nation's Climate Crisis Action Plan.

5. Zero Carbon to Low Emission Energy Sources

Reaching net zero carbon dioxide emissions is a fast-growing, global environmental policy goal. In a summary for policymakers, the International Energy Agency highlights a call to action for all governments to re-evaluate and adjust their energy and climate policies to "reach net zero carbon emissions by 2050" [41]. This report indicates the pathway to successfully reaching net zero involving a major pivot away from fossil fuels and an equally significant increase in renewable energy sources, supplemented by nuclear power. Many renewable energy sources are zero carbon emitters, however, just because an energy source is considered renewable does not mean that it is also carbon-free. To

qualify as a zero-carbon, carbon-free, or zero- to low-emission energy source, a resource must be able to produce energy without generating carbon emissions while running [42]. Examples of renewable energy that also naturally produce low carbon emissions are solar, wind, geothermal, some hydroelectric, and some types of bioenergy. Nuclear energy is an example of a non-renewable energy since its primary power source, uranium, is a limited resource; inversely, it also qualifies as a zero-carbon energy source because it does not produce carbon dioxide while producing electricity [42]. While renewable energy is usually considered carbon-free and a cleaner alternative to fossil fuel energy, renewable energy is not without its drawbacks. Solar energy requires sunlight, which is not consistently available and has variation based on geographical location [43]. Solar energy also has relatively rapid panel deterioration and high costs of production, panel installation, and maintenance, may require a large number of panels to provide adequate amounts of power, and uses environmental pollutants in the construction and installation of the solar panels (including cadmium, lead, and sulfuric acid) [43]. According to the Energy Information Administration (EIA), solar energy accounted for about 12% of the electricity used by the U.S. in 2021 [44].

Another renewable energy source, wind energy, requires the presence of wind, which is not consistently available. There are also concerns about wind energy posing a threat to wildlife and their habitats, and the sound and aesthetics of wind turbines [45]. That being said, in 2021, the EIA reported that wind energy produced roughly 27% of the U.S.'s renewable energy. Historically, hydropower has been the leading producer of renewable energy in the U.S., however, the 2021 energy consumption report produced by the EIA shows that hydropower is now the second greatest contributor of renewable energy-producing 19% of the total energy consumed by the U.S. of renewable sources [44]. Disadvantages such as the prevention of fish migration and spawning, the decrease in water quality and flow of downstream rivers, and upstream flooding have caused a nation-wide call to transfer energy dependency from this source to other renewable options [46]. According to the American Rivers organization, 69 dams have been removed across the U.S. Recently, there has been a large demand and political movement to remove the four main dams located on the Lower Snake River in order to conserve Idaho's wild salmon populations [47–50]. Additionally, the assumption of water availability is becoming questionable as many geographical locations are experiencing changing and unreliable weather patterns such as frequent and long-lasting drought [51].

While the impacts of all energy sources can be debated, perhaps the biggest question is whether nuclear energy should be included in a zero-carbon energy future. Emissions produced by nuclear power plants are comparable or less than those produced by other renewable energy sources. Based on 2018 data, nuclear power is one of the leading producers of low-carbon energy, second only to hydropower [52]. Estimates from 19 studies that tried to determine the amount of greenhouse gas emissions from nuclear energy showed a range from 1.4 g to 288 g of C02e/KWh [53]. Nuclear energy is typically portrayed as a clean and reliable source of energy. However, the number of nuclear energy outages due to climate events has been increasing over the past three decades [54], and there are concerns about the safety of nuclear energy with extreme climate events [55]. The U.S. Office of Nuclear Energy does outline several challenges associated with nuclear power. Current challenges of nuclear energy include public perception and awareness, the association with historical nuclear events, the storage and disposal of nuclear waste, the lengthy construction and regulation timelines of new power plants, affordability of new construction projects, and high operational costs [56].

Nuclear energy has many opponents, including environmental advocacy groups and organizations like Greenpeace, Green America, Friends of the Earth, Natural Resources Defense Council, Snake River Alliance, and the Sierra Club, which all hold a long-standing opposition to the opinion that nuclear energy is part of the solution to reducing carbon emissions. Their argument against nuclear energy centers around issues of nuclear waste

storage and disposal, national security, reactor accidents, cancer risks, and competition with renewables, as well as the harsh economic impact of building new reactors [57–62].

Other opposition groups of nuclear energy include top carbon emitters and oil producers [63] such as The American Petroleum Institute, National Coal Policy Council, Pennsylvania Independent Oil and Gas Association, Marcellus Shale Coalition, and other corporations allied with the fossil fuel industry. The fossil fuel industry's opposition to nuclear likely stems from energy market competition. As nuclear energy becomes a significant part of the energy industry, there is anticipated to be less need and a lower value for fossil fuels. A 2020 Gallup poll noted that top users of fossil fuel also showed more skepticism towards climate change; 21% of people in the U.S. believe that there is zero threat from climate change [64].

Public perception of nuclear energy fluctuates, with more negative views following reactor incidents. Events such as the Three Mile Island accident in Pennsylvania, United States (1979), the Chernobyl disaster in Pripyat, Ukraine (1986), and the Fukushima Daiichi disaster in Ōkuma, Fukushima Prefecture, Japan (2011) were followed with increased negative perceptions about nuclear energy [65]. Public perceptions of nuclear power as an energy source prior to these incidents was recorded by a 2010 Gallup poll which showed a 62% favorability (those who strongly favored and somewhat favored) to nuclear energy; a 2012 Gallup report following the Fukushima disaster showed a drop to 57% favorability from the 2011 poll (a 13% drop in positive public perception of nuclear power in those who strongly favored and somewhat favored nuclear energy) [66]. An updated polling of favorability in 2022 indicates that the percentage of those who strongly favor and somewhat favor nuclear energy is around 51%, which is lower than in 2012; however, it is higher than the 49% who favored nuclear energy in 2019 [66].

In this study, we examine current perceptions of nuclear energy as part of the zero–carbon energy mix needed for a net-zero future.

6. Methods

This study is a secondary data analysis from a larger study which examined perceptions of nuclear energy. Participants were recruited through two popular news outlets in eastern Idaho (East Idaho News and the Idaho State Journal). This call for participants was also shared on social media. As a result, the survey was intended for an Idaho audience, and survey questions reflected this orientation. All participants provided written informed consent. This study was approved by the Idaho State University institutional review board.

7. Measurements

Climate change. All participants were asked "How concerned, if at all, are you about climate change (sometimes referred to as global warming)?" The response options were as follows: "not at all concerned", "not very concerned", "fairly concerned", "very concerned", and "don't know".

Radioactive waste. To determine concerns over radioactive waste, participants were asked to respond to the same statement Bickerstaff [28] used in their focus groups, "The idea of radioactive waste fills me with dread." Response options were as follows: "agree", "neutral", "disagree", and "don't know".

Perceptions of nuclear energy and the environment. Participants were asked for their position on the statements of "Nuclear energy is a clean energy source", "Nuclear energy may be part of the solution to climate change", and "I am willing to accept the building of new nuclear power stations if it is environmentally friendly and had a zero-carbon footprint". The response options for these three questions were as follows: "disagree", "neutral", "agree", and "don't know". Participants were also asked their position on the statement that Yeo [67] asked, "Nuclear power may lead to more pollution and environmental contamination". While Yeo had used 10 response options ranging from "Do not agree at all" to "Agree very much", the response options of "disagree", "neutral", "agree", and "don't know" were used for consistency with the prior three questions. Participants

were also asked, "Do you think nuclear energy is a zero-carbon energy?". Response options for this question were as follows: "yes", "no", and "don't know".

Demographics. Participants' age, sex, race, ethnicity, and income were obtained via self-report. Participant race/ethnicity was classified as Hispanic, non-Hispanic White, and Other/unknown. Participant zip code and INL employment status was also obtained via self-report.

8. Statistical Analysis

Chi-square tests were used to determine the bivariate associations of concerns around climate change and nuclear waste with participant demographics and perceptions of nuclear energy and the environment. Logistic regressions were then run to determine how concerns around climate change and nuclear waste were associated with perceptions of nuclear energy, after controlling for demographics. Each perception of nuclear energy and the environment was predicted by concerns around climate change and nuclear waste, after controlling for participant age, sex, race/ethnicity, and income. While concerns around climate change and nuclear waste were associated, the adjusted generalized variance inflation factors were all less than 1.1, indicating no concern of multicollinearity. A latent class analysis was then run to identify segments of the respondents based on their responses to the five response variables using the poLCA R package. The statistical software r (v 4.1.1) was used for all analyses. Statistical significance was set at $p < 0.01$.

9. Results

A total of 6151 participants started the survey. To our surprise, participants were from across the US, and not just Eastern Idaho; approximately 60% of participants who took the survey were not from Idaho. A total of 3757 participants responded to the question on climate change and nuclear waste, and the six questions relating to nuclear energy and the climate. After excluding 485 participants who reported "don't know" for any of these questions, an additional 1595 participants whose zip code was within a 50-mile radius of a nuclear reactor or who worked for INL, and 61 participants with unknown demographics or who reported a non-male/female gender, a total of 1616 participants remained (41% female, 44% non-Hispanic White). Comparing some demographics of our sample with US Census population data of Idaho [68] shows that males and Hispanics were overrepresented in our sample.

The majority of participants reported being not very concerned (31%) or fairly concerned (33%) of climate change, with few reporting being not at all concerned (14%) or very concerned (21%; Table 1). Participants were nearly equally split between disagreement (34%), neutrality (31%), and agreement (35%) towards the statement that radioactive waste filled them with dread. There was a significant association between concern around climate change and concern around nuclear waste ($p < 0.001$). The majority (54%) of participants who were not at all concerned about climate change stated that they disagreed that the idea of radioactive waste filled them with dread (20% agreed with the statement). In comparison, 45% of participants who were very concerned about climate change agreed that the idea of radioactive waste filled them with dread (29% disagreed with the statement).

Table 1. The association between concern about climate change and radioactive waste for the 1616 participants in the study.

		How Concerned, if at All, Are You about Climate Change (Sometimes Referred to as Global Warming)?			
	Total	**Not at All Concerned**	**Not Very Concerned**	**Fairly Concerned**	**Very Concerned**
	N = 1616	**N = 232 (14%)**	**N = 503 (31%)**	**N = 535 (33%)**	**N = 346 (21%)**
The idea of radioactive waste fills me with dread, n (%)					
Disagree	555 (34)	125 (54)	173 (34)	157 (29)	100 (29)
Neutral	503 (31)	60 (26)	139 (28)	212 (40)	92 (27)
Agree	558 (35)	47 (20)	191 (38)	166 (31)	154 (45)

While only half (50%) of the participants agreed that nuclear energy was a clean energy source, the majority of participants (74%) thought that nuclear energy was a zero-carbon energy (Table 2). Only 12% of participants disagreed that nuclear energy may be part of the solution to climate change, and 63% of participants agreed that they were willing to accept the building of new nuclear power stations if they were environmentally friendly and had a zero-carbon footprint. However, 42% of participants also agreed that nuclear power may lead to more pollution and environmental contamination.

At the bivariate level, all the questions for perceptions of nuclear energy and participant demographics were significantly associated with concern around climate change and radioactive waste (all $p < 0.001$; Table 2). In general, as concern about climate change increased, the percentage of participants who thought nuclear energy was a zero-carbon energy decreased, and a greater percentage of these participants (those more concerned about climate change) thought that nuclear energy may be part of the solution to climate change, were willing to accept the building of new nuclear power stations if they were environmentally friendly and had a zero-carbon footprint, and agreed that nuclear power may lead to more pollution and environmental contamination. Furthermore, as concern regarding nuclear waste increased, the percentage of participants who agreed that nuclear energy was clean, zero-carbon, and part of the solution to climate change decreased, while the percentage of participants who agreed that nuclear power may lead to more pollution and environmental contamination increased.

After controlling for demographics, concern around climate change and radioactive waste remained a significant predictor of the five variables examining perceptions of nuclear energy and the environment. Compared to participants who were not at all concerned about climate change, participants who were very concerned about climate change had lower odds of believing that nuclear energy was a clean energy source (OR = 2.54, 99% CI = 1.51, 4.28), and lower odds of believing that nuclear energy was a zero-carbon energy (OR = 0.35, 99% CI = 0.19, 0.61; Table 3). Participants who were very concerned about climate change had higher odds of agreeing that nuclear energy may be part of the solution to climate change (OR = 4.33, 99% CI = 2.61, 7.28), being willing to accept the building of new nuclear power stations if they were environmentally friendly and had a zero-carbon footprint (OR = 5.03, 99% CI = 3.02, 8.51), and agreeing that nuclear energy may lead to more pollution and environmental contamination (OR = 4.01, 99% CI = 2.27, 7.31), when compared to participants who were not at all concerned about climate change.

Table 2. Participant demographics and perceptions of nuclear energy and the environment by concern about climate change and radioactive waste.

Characteristic	Overall N = 1616	How Concerned, if at All, Are You about Climate Change (Sometimes Referred to as Global Warming)?				The Idea of Radioactive Waste Fills Me with Dread		
		Not at All Concerned N = 232 (14%)	Not Very Concerned N = 503 (31%)	Fairly Concerned N = 535 (33%)	Very Concerned N = 346 (21%)	Disagree N = 555 (34%)	Neutral N = 503 (31%)	Agree N = 558 (35%)
Age (years)								
18 to 24	168 (10)	35 (15)	50 (10)	54 (10)	29 (8)	64 (12)	61 (12)	43 (8)
25 to 34	790 (49)	81 (35)	285 (57)	262 (49)	162 (47)	201 (36)	234 (47)	355 (64)
35 to 44	404 (25)	58 (25)	108 (21)	154 (29)	84 (24)	157 (28)	134 (27)	113 (20)
45 to 54	126 (8)	21 (9)	35 (7)	33 (6)	37 (11)	58 (10)	38 (8)	30 (5)
54 or older	128 (8)	37 (16)	25 (5)	32 (6)	34 (10)	75 (14)	36 (7)	17 (3)
Sex								
Female	665 (41)	67 (29)	246 (49)	213 (40)	139 (40)	179 (32)	198 (39)	288 (52)
Male	951 (59)	165 (71)	257 (51)	322 (60)	207 (60)	376 (68)	305 (61)	270 (48)
Race/ethnicity								
non-Hispanic White	719 (44)	118 (51)	177 (35)	251 (47)	173 (50)	363 (65)	185 (37)	171 (31)
Hispanic	601 (37)	68 (29)	245 (49)	189 (35)	99 (29)	103 (19)	224 (45)	274 (49)
Other/Unknown	296 (18)	46 (20)	81 (16)	95 (18)	74 (21)	89 (16)	94 (19)	113 (20)
Income								
$40,000 or less	272 (17)	37 (16)	68 (14)	96 (18)	71 (21)	98 (18)	92 (18)	82 (15)
$40,001 to $60,000	286 (18)	32 (14)	82 (16)	107 (20)	65 (19)	114 (21)	83 (17)	89 (16)
$60,001 to $80,000	327 (20)	48 (21)	89 (18)	134 (25)	56 (16)	112 (20)	124 (25)	91 (16)
$80,001 to $100,000	316 (20)	69 (30)	84 (17)	90 (17)	73 (21)	105 (19)	104 (21)	107 (19)
$100,001 to $150,000	204 (13)	36 (16)	52 (10)	68 (13)	48 (14)	91 (16)	66 (13)	47 (8)
More than $150,000	211 (13)	10 (4)	128 (25)	40 (7)	33 (10)	35 (6)	34 (7)	142 (25)
Nuclear energy is a clean energy source								
Agree	808 (50)	135 (58)	176 (35)	269 (50)	228 (66)	424 (76)	210 (42)	174 (31)
Neutral	582 (36)	41 (18)	288 (57)	198 (37)	55 (16)	101 (18)	235 (47)	246 (44)
Disagree	226 (14)	56 (24)	39 (8)	68 (13)	63 (18)	30 (5)	58 (12)	138 (25)
Do you think nuclear energy is a zero-carbon energy?								
Yes	1190 (74)	196 (84)	427 (85)	360 (67)	207 (60)	459 (83)	383 (76)	348 (62)
No	426 (26)	36 (16)	76 (15)	175 (33)	139 (40)	96 (17)	120 (24)	210 (38)
Nuclear energy may be part of the solution to climate change								
Agree	827 (51)	100 (43)	204 (41)	304 (57)	219 (63)	411 (74)	221 (44)	195 (35)
Neutral	602 (37)	99 (43)	252 (50)	174 (33)	77 (22)	115 (21)	239 (48)	248 (44)
Disagree	187 (12)	33 (14)	47 (9)	57 (11)	50 (14)	29 (5)	43 (9)	115 (21)
Nuclear power may lead to more pollution and environmental contamination								
Agree	679 (42)	39 (17)	233 (46)	234 (44)	173 (50)	98 (18)	196 (39)	385 (69)
Neutral	479 (30)	58 (25)	159 (32)	186 (35)	76 (22)	139 (25)	224 (45)	116 (21)
Disagree	458 (28)	135 (58)	111 (22)	115 (21)	97 (28)	318 (57)	83 (17)	57 (10)
I am willing to accept the building of new nuclear power stations if it is environmentally friendly and had a zero-carbon footprint								
Agree	1018 (63)	115 (50)	311 (62)	321 (60)	271 (78)	422 (76)	234 (47)	362 (65)
Neutral	442 (27)	60 (26)	149 (30)	180 (34)	53 (15)	103 (19)	219 (44)	120 (22)
Disagree	156 (10)	57 (25)	43 (9)	34 (6)	22 (6)	30 (5)	50 (10)	76 (14)

Table 3. Logistic regression results predicting perceptions of nuclear energy and the (N = 1616).

	Nuclear Energy Is a Clean Energy Source (Agree)			Do You Think Nuclear Energy Is a Zero Carbon Energy? (Yes)			Nuclear Energy May Be Part of the Solution to Climate Change (Agree)			Nuclear Power May Lead to More Pollution and Environmental Contamination (Agree)			I Am Willing to Accept the Building of New Nuclear Power Stations if It Is Environmentally Friendly and Had a Zero-Carbon Footprint (Agree)		
Characteristic	**OR**	**99% CI**	***p*-Value**	**OR**	**99% CI**	***p*-Value**	**OR**	**99% CI**	***p*-Value**	**OR**	**99% CI**	***p*-Value**	**OR**	**99% CI**	***p*-Value**
How concerned, if at all, are you about climate change (sometimes referred to as global warming)?															
Not at all concerned	(ref)			(ref)			(ref)			(ref)			(ref)		
Not very concerned	0.53	0.32, 0.87	**<0.001**	0.83	0.45, 1.50	0.435	1.62	1.01, 2.63	**0.009**	2.74	1.56, 4.93	**<0.001**	1.57	0.98, 2.51	0.014
Fairly concerned	1.12	0.69, 1.80	0.557	0.40	0.22, 0.68	**<0.001**	3.25	2.02, 5.28	**<0.001**	3.18	1.84, 5.65	**<0.001**	2.15	1.36, 3.43	**<0.001**
Very concerned	2.43	1.44, 4.12	**<0.001**	0.32	0.18, 0.57	**<0.001**	4.44	2.66, 7.51	**<0.001**	3.83	2.16, 7.01	**<0.001**	4.96	2.93, 8.51	**<0.001**
The idea of radioactive waste fills me with dread															
Disagree	(ref)			(ref)			(ref)			(ref)			(ref)		
Neutral	0.24	0.16, 0.35	**<0.001**	0.62	0.41, 0.95	**0.004**	0.25	0.17, 0.37	**<0.001**	2.27	1.53, 3.39	**<0.001**	0.24	0.16, 0.35	**<0.001**
Agree	0.14	0.09, 0.21	**<0.001**	0.25	0.17, 0.38	**<0.001**	0.19	0.13, 0.28	**<0.001**	6.72	4.52, 10.1	**<0.001**	0.37	0.24, 0.55	**<0.001**
Age															
18 to 24	(ref)			(ref)			(ref)			(ref)			(ref)		
25 to 34	1.63	0.97, 2.75	0.016	0.99	0.55, 1.73	0.966	0.89	0.54, 1.46	0.548	0.85	0.51, 1.44	0.433	1.06	0.64, 1.74	0.768
35 to 44	1.65	0.95, 2.88	0.020	0.72	0.39, 1.29	0.151	0.87	0.51, 1.48	0.499	1.18	0.68, 2.06	0.445	0.95	0.55, 1.61	0.789
45 to 54	1.46	0.72, 2.98	0.169	0.75	0.34, 1.63	0.331	1.19	0.60, 2.38	0.507	0.77	0.37, 1.61	0.364	0.98	0.49, 2.00	0.954
54 or older	1.83	0.88, 3.88	0.036	0.69	0.32, 1.52	0.225	1.69	0.82, 3.54	0.064	0.4	0.17, 0.93	0.006	1.31	0.63, 2.79	0.343
Sex															
Female	(ref)			(ref)			(ref)			(ref)			(ref)		
Male	1.32	0.97, 1.80	0.022	0.99	0.71, 1.37	0.927	1.18	0.87, 1.59	0.163	0.61	0.45, 0.84	**<0.001**	0.71	0.52, 0.97	**0.004**
Race/ethnicity															
non-Hispanic White	(ref)			(ref)			(ref)			(ref)			(ref)		
Hispanic	0.41	0.29, 0.59	**<0.001**	1.88	1.27, 2.82	**<0.001**	0.69	0.48, 0.97	**0.005**	1.97	1.37, 2.84	**<0.001**	0.68	0.47, 0.97	**0.005**
Other Unknown	0.64	0.42, 0.95	**0.004**	0.88	0.58, 1.35	0.445	0.70	0.47, 1.05	0.022	1.70	1.12, 2.59	**0.001**	0.76	0.51, 1.15	0.088
Income															
$40,000 or less	(ref)			(ref)			(ref)			(ref)			(ref)		
$40,001 to $60,000	0.86	0.53, 1.42	0.448	1.37	0.81, 2.33	0.125	0.79	0.48, 1.27	0.200	0.65	0.39, 1.08	0.030	0.56	0.34, 0.92	**0.003**
$60,001 to $80,000	0.69	0.42, 1.11	0.043	0.91	0.55, 1.50	0.629	0.73	0.46, 1.16	0.080	0.72	0.44, 1.19	0.092	0.48	0.30, 0.78	**<0.001**
$80,001 to $100,000	0.84	0.51, 1.35	0.338	1.06	0.64, 1.77	0.757	0.63	0.39, 1.01	0.012	0.79	0.48, 1.30	0.220	0.61	0.38, 1.00	**0.010**
$100,001 to $150,000	1.02	0.59, 1.78	0.913	1.27	0.71, 2.30	0.287	1.05	0.61, 1.82	0.808	0.82	0.46, 1.44	0.367	0.93	0.53, 1.64	0.747
More than $150,000	0.83	0.45, 1.55	0.450	4.43	2.08, 10.2	**<0.001**	0.46	0.26, 0.83	**<0.001**	2.05	1.09, 3.87	**0.003**	3.90	1.95, 8.12	**<0.001**

Bold indicates statistical significance ($p < 0.01$).

Participants who agreed that the idea of radioactive waste filled them with dread had significantly lower odds of agreeing that nuclear energy was a clean energy source (OR = 0.15, 99% CI = 0.10, 0.22) or a zero-carbon energy (OR = 0.27, 99% CI = 0.17, 0.40), when compared to participants who disagreed that the idea of radioactive waste filled them with dread. Compared to participants who disagreed that the idea of radioactive waste filled them with dread, participants who agreed that the idea of radioactive waste filled them with dread also had lower odds of agreeing that nuclear energy may be part of the solution to climate change (OR = 0.18, 99% CI = 0.12, 0.26), and being willing to accept the building of new nuclear power stations if they were environmentally friendly and had a zero-carbon footprint (OR = 0.43, 99% CI = 0.29, 0.63). Conversely, participants who agreed that the idea of radioactive waste filled them with dread had significantly higher odds of agreeing that nuclear energy may lead to more pollution and environmental contamination (OR = 7.14, 99% CI = 4.84, 10.7), compared to their counterparts who disagreed with the same statement.

The latent class analysis BIC showed diminishing returns after three classes had been included. These three classes showed participants whose perceptions of nuclear energy and the environment were favorable, neutral, and negative (Table 4). Roughly 40% of participants were in the "favorable" class, compared to 52% in the "neutral" class and 8% in the "negative" class. As expected, there was a significant association between these three classes and concern around climate change ($p < 0.001$) and nuclear waste ($p < 0.001$; Table 5). Participants who were in both the favorable and unfavorable categories tended to be concerned about climate change, while participants who were in the neutral category tended to be not very concerned or only fairly concerned (not very concerned). In contrast, participants who were in the favorable category tended to disagree that the idea of radioactive waste filled them with dread (58%), while participants who were in the unfavorable category agreed that radioactive waste filled them with dread (80%).

Table 4. Latent class analysis results showing the probabilities of belonging to each of the three classes.

Nuclear energy is a clean energy source			
	Agree	Neutral	Disagree
class 1: favorable	0.98	0.02	0.00
class 2: neutral	0.20	0.67	0.12
class 3: unfavorable	0.04	0.00	0.96
Do you think nuclear energy is a zero-carbon energy?			
	No	Yes	
class 1: favorable	0.19	0.81	
class 2: neutral	0.23	0.77	
class 3: unfavorable	0.87	0.13	
Nuclear energy may be part of the solution to climate change			
	Agree	Neutral	Disagree
class 1: favorable	0.90	0.08	0.02
class 2: neutral	0.27	0.65	0.09
class 3: unfavorable	0.16	0.06	0.78
Nuclear power may lead to more pollution and environmental contamination			
	Agree	Neutral	Disagree
class 1: favorable	0.23	0.21	0.56
class 2: neutral	0.50	0.40	0.10
class 3: unfavorable	0.90	0.01	0.09
I am willing to accept the building of new nuclear power stations if it is environmentally friendly and had a zero-carbon footprint			
	Agree	Neutral	Disagree
class 1: favorable	0.89	0.10	0.00
class 2: neutral	0.48	0.41	0.12
class 3: unfavorable	0.31	0.25	0.44

Table 5. Association between the three latent classes and concern around climate change and radioactive waste.

	Class 1: Favorable N = 648 (40%)	**Class 2: Neutral N = 842 (52%)**	**Class 3: Unfavorable N = 126 (7.8%)**
How concerned, if at all, are you about climate change (sometimes referred to as global warming)?			
Not at all concerned	106 (16%)	116 (14%)	10 (8%)
Not very concerned	140 (22%)	342 (41%)	21 (17%)
Fairly concerned	207 (32%)	284 (34%)	44 (35%)
Very concerned	195 (30%)	100 (12%)	51 (40%)
The idea of radioactive waste fills me with dread			
Disagree	376 (58%)	172 (20%)	7 (6%)
Neutral	140 (22%)	345 (41%)	18 (14%)
Agree	132 (20%)	325 (39%)	101 (80%)

Both associations were highly significant, $p < 0.001$.

10. Discussion

This study examined how concern around climate change and radioactive waste was associated with perceptions of nuclear energy and the environment. While participants tended to agree that nuclear energy was zero-carbon, less participants agreed that nuclear energy was a clean energy source. As concern around climate change increased participants were correspondingly more open to nuclear energy; however, concern around radioactive waste was associated with less acceptance of nuclear energy. There was clear concern around pollution and environmental contamination from nuclear power. However, the majority of participants who were not concerned with climate change also did not believe that nuclear power would lead to more environmental contamination. Overall, this study suggests that few participants (8%) had negative perceptions of nuclear energy and the environment, with the majority of participants being either favorable (40%) or neutral (52%).

There was relatively consistent agreement around nuclear energy being a clean energy source among those who were not at all concerned (58% agree), and very concerned (66% agree), about climate change. However, as concern for climate change increased, the agreement that nuclear energy was a zero-carbon energy source decreased (84% agree to 60%). This may indicate that, while a clean energy source, nuclear power still has a perceived negative impact to the climate crisis. Potentially, concerns around nuclear energy that prevent it from being seen as a clean and zero-carbon energy source are from criticisms such as the energy required to obtain the fuel for nuclear energy, the carbon footprint of large concrete buildings, and the waste products after energy creation.

This study found that participants were fairly evenly split on their concern over climate change. Those who were more concerned with climate change also seemed more accepting of nuclear energy as part of our energy future, and this is an interesting finding since those with more supportive views of environmental protection traditionally tend to not support nuclear energy [18–21]. While not reaching the public popularity it had between 1950 and the early 1970s prior to incidents such as Three Mile Island in 1979 [16], there are international studies that show conditional or reluctant support for nuclear energy as a solution to climate change [26–28]. While participants who were more concerned about climate change were more open to nuclear energy, even these participants may still favor other forms of energy. More research is needed to determine how favorability towards nuclear energy compares with favorability towards other low-carbon energy sources. Subsequent studies should also include in-depth questions on attitudes towards environmental concerns, such that the association between environmental concerns and nuclear energy can be better understood.

Concerns around pollution and environmental contamination from nuclear energy are often dismissed by those promoting nuclear energy. This study shows that a substantial amount of concern for environmental issues exists, particularly among those who are

also concerned about climate change and radioactive waste. The discussion opposing nuclear energy has included environment protection for many years [16], and this study is consistent with the prior studies that showed a negative attitude to nuclear energy among those who were concerned about the environment [18–21]. Conversely, this study also shows that over half of the participants who were not concerned about climate change (58%) or radioactive waste (57%) disagreed that nuclear power may lead to more pollution and environmental contamination. This finding is partially explained by the ongoing political identity-based political polarization in the U.S. (Mason, 2015), where individuals fully buy into a topic regardless of scientific data [8].

This study drew a large number of participants from across the United States and excluded those who self-identified as being at a zip code that was within 50 miles of a nuclear reactor or as an INL employee. However, the outreach was through eastern Idaho-located news outlets, which could indicate that most respondents had some sort of relationship with eastern Idaho where Idaho National Laboratory is located. Results from this same study have shown that respondents living near INL were more positive to nuclear energy than respondents who lived further away [6]. While participants from across the US were part of the study, participants in this study likely had more knowledge of, and potentially comfort with, nuclear energy than the general US population based on their potential association with eastern-Idaho.

Additionally, using media outlets as the outreach source could have resulted in participants who are more accustomed to reading media, presenting a respondent pool who had received more information (either pro or con). Drawing participants in alternative ways could also provide more depth to the results with expanded geographical outreach.

As worldwide concerns for climate change grow and governments and industry seek to find viable solutions to provide power to our ever-growing energy needs, acceptance for nuclear energy is a critical topic. Alternative low- or no-carbon energy sources are intermittent or provide only limited power, and nuclear energy is expected to be a key part of the world's energy future [38]. At the same time, in democratic countries, if populations are not willing to accept nuclear power as part of the solution, it will be difficult for governments to include nuclear energy in a low- to no-carbon future. By looking at various perceptions of nuclear energy, this study identifies areas which remain problematic and shows areas of acceptance towards nuclear energy. It might be tempting to think that our data will help policy makers craft messages that would better appeal to individuals who see climate change as a problem. However, the "science deficit" model of science communication [9] calls into question this conclusion. Beliefs about issues like nuclear energy are not easily changed by more information or new marketing messages. Instead, our policy implications suggests that nuclear energy advocates must continue to work in issues related to nuclear waste and nuclear safety, ensuring climate change advocates that nuclear energy is safe and that long-term waste disposal is possible. As Simis, et al. [9] argue this is best accomplished through scientists finding more effective ways to communicate their science. Then, scientists need to work with social scientists to better understand how individuals use values and beliefs in decision making. All these suggestions work best in two-way dialogue and working groups among scientists and community groups who might be skeptical about the risks and benefits of nuclear energy.

Both governments and industries are researching myriad energy sources to provide a low-carbon energy future. Public perceptions and attitudes towards all possible energy sources will inform and direct government spending, university research, and workforce development to develop and support the world's increasing demands for energy. Additional studies into public attitudes and perceptions will help build an understanding of the content and areas of need for public outreach to keep the public educated and informed on the benefits—and challenges—for the world's energy future.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/en16042025/s1. File S1. Survey Questions and Survey Responses.

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