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Optimizing renewable energy: advanced strategies for enhanced efficiency and sustainability

RISK PERCEPTION, KNOWLEDGE, AND BEHAVIOR TOWARDS NUCLEAR ENERGY

(BRAZIL)

PERCEPÇÃO DE RISCO, CONHECIMENTO E COMPORTAMENTO FRENTE À ENERGIA NUCLEAR (BRASIL)

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ABSTRACT

The goal of this article is to present the methodological preparation of a study on the perception of risk, knowledge, and behavior towards nuclear energy in Brazil. By mapping the main fears, doubts, and knowledge gaps within the academic community, the study aims to generate contributions for the future development of an action plan focused on scientific dissemination and university extension. The ongoing research seeks to interview the university population (professors, students, administrative staff, and operational technicians) of the Federal University of ABC (UFABC), located in the State of São Paulo, Brazil. After data collection, the analysis will be structured in four phases with the objective of extracting various important pieces of information, such as analyzing and correlating specific population groups with particular questions from the questionnaire. These results will allow for the creation of a diagnosis regarding nuclear energy in the surveyed community. The final purpose is to mitigate misinformation and broaden public acceptance of nuclear technology, grounding it in a clearer and more conscious debate.

Keywords: nuclear energy; nuclear risk; perception; Brazil.

RESUMO

O objetivo deste artigo é apresentar a preparação metodológica de uma pesquisa sobre a percepção de risco, conhecimento e comportamento frente à energia nuclear no Brasil. A partir do mapeamento dos principais receios, dúvidas e lacunas de conhecimento da comunidade acadêmica, o estudo visa gerar contribuições para futura elaboração de um plano de ação focado em divulgação científica e extensão universitária. A pesquisa em construção busca entrevistar a população universitária (professores, estudantes, técnicos administrativos e técnicos operacionais) da Universidade Federal do ABC (UFABC), situada no Estado de São Paulo, Brasil. Após a coleta de dados, a análise será estruturada em quatro fases com o objetivo de extrair diversas informações importantes, tais como analisar e correlacionar determinados grupos da população com alguma pergunta específica do questionário. Estes resultados permitirão criar um diagnóstico sobre a energia nuclear na comunidade pesquisada. O propósito final é mitigar a desinformação e ampliar a aceitação pública da tecnologia nuclear, fundamentando-a em um debate mais claro e consciente.

Palavras-chave: energia nuclear; risco nuclear; percepção; Brasil.



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1 INTRODUCTION

Brazil has already begun the development of a Nuclear Microreactor (MMR). To develop the means and technology necessary for manufacturing MMRs in Brazil, a union of private companies, universities, research institutes, and a directorate of the Brazilian Navy was formed (Zaparolli, 2025). The MMR is a smaller piece of equipment than conventional nuclear reactors that generate energy through the fission of the atomic nucleus.

The Brazilian project envisions the development of MMRs with a generation capacity of 1 to 5 megawatts (MW) of electrical energy (Orlandi et al., 2024). It is estimated that each megawatt is sufficient to supply about a thousand people. In Brazil, about 1/5 of the country's municipalities have a population close to 5,000 inhabitants. Thus, each municipality could be served by one MMR. MMR is remotely controlled, meaning the operator is located at a distance, and each MMR is transportable and the size of a container. MMR could be used to replace diesel electricity generators that supply isolated communities, industries, hospitals, datacenters, and other establishments that need an alternative or complementary system to the conventional electrical supply (Zaparolli, 2025).

Globally, MMR projects are relatively new. Besides the technical issues themselves, at this initial stage, research also focuses on postulated accident scenarios. That is, the safety issue considers the assessments and experiences from conventional reactors to prevent unknown threats, potential dangers, vulnerabilities, influencing factors, and dependency interactions for the new MMRs (Antonello et al., 2023). Basically, the ongoing safety analyses on MMRs allow for:

- i) Identify the dangers of the nuclear microreactor and the corresponding safety restrictions and limits;
- ii) Identify previously unknown threats; iii) Investigate a variety of accident scenarios resulting from the combination of identified loss events; iv) Evaluate the most relevant components, characteristics, and parameters; v) Quantify the probabilities of exceeding safety limits during accident scenarios and identify the parameters that contribute most to this; vi) Estimate ranges and interactions of hidden unsafe parameters; vii) Provide a dynamic assessment of the risk profile; viii) Identify the tolerance time during characteristic accident scenarios (ANTONELLO et al. 2023, p. 13).

In this context of the new technology of MMR and also of the continued operation of Conventional Nuclear Power Plants for electricity production, it is necessary to discuss an object of controversy that always surrounds nuclear energy for electricity generation: social, environmental, and technological fear. Especially after the Chernobyl (1986) and Fukushima (2011) accidents, the general public associates nuclear energy with risks, which according to experts, are disproportionate. The objective of this article is to present the methodological preparation of a study on the perception of risk, knowledge, and behavior towards nuclear energy in Brazil. By mapping the main fears, doubts, and knowledge gaps within the academic community, the study aims to generate contributions for the future development of an action plan focused on scientific dissemination and university extension. The final purpose is to mitigate misinformation and broaden public acceptance of nuclear technology, grounding it in a clearer and more conscious debate.



2 METHODOLOGY

In the pursuit of conducting an assessment on the perception of risk, knowledge, and behavior towards nuclear energy in Brazil, this research takes as its methodological starting point the analysis of the study by Perez et al. (2020). Perez et al. (2020) produced an investigation into the perception of nuclear risk in France using an interview method. They interviewed two populations: 1,240 firefighters (specialists) and 1,075 university students (non-specialists) from the University of Côte d'Azur (UCA).

After affirming that the interview would be the study method adopted to investigate the objective of the ongoing study, the appropriate population for the scientific purposes was defined. The research under development seeks to interview the university population (professors, students, administrative staff, and operational technicians) of the Federal University of ABC (UFABC), located in the State of São Paulo, Brazil.

The interview is composed of multiple-choice questions and one open-ended question, where the interviewee is asked for their suggestion for the questionnaire. Some questions have the single option of selecting only one alternative. Other questions have the option to select several applicable alternatives for each question. The interview will be launched on an online platform and sent by email. The questionnaire was tested at the Interdisciplinary Laboratory of Nuclear Energy at UFABC (Nuc-Lab), where the research is being developed. The original questionnaire applied at UCA (Perez et al., 2020) was adapted for the issues of Brazilian nuclear energy. It is formatted in three parts:

- a) Perception of nuclear energy in Brazil, issues of safety, technological and environmental risks, in addition to aspects of the legislation employed;
- b) The interviewees' knowledge about radioactivity and their comprehension of scientific information on the topic;
- c) Relations between perception and knowledge that generate behavior, characterizing the sample of each subgroup: general information, knowledge regarding nuclear alerts, age.

2.1 Structure of the Questionnaire

At this stage of the research, the following are the questions developed in the preparation of the questionnaire:

a) Risk Perception

Does the nuclear industry scare you? (Yes, No, or I don't know). If yes, for what reasons? (Proliferation of the atomic bomb, International diplomatic tension, Out of control chain reactions, Radioactivity is invisible, Fear of the effects of radioactivity, Long-term contamination, Consequences of terrorist acts, Aging of the power plants, Radioactive waste remains dangerous for millennia). How confident are you about the future of nuclear energy? What is your level of trust in the Brazilian nuclear industry? Are the terms 'nuclear' and 'radioactivity' related? Has the perception of nuclear risk changed since the Fukushima, Chernobyl, or Three Mile Island accidents? Who are the operators of the Brazilian nuclear industry? (Options include: Brazilian Nuclear Energy Association (ABEN); Brazilian Association for the Development of Nuclear Activities (ABDAN); National Nuclear Safety Authority (ANSN); National Nuclear Energy Commission (CNEN); Eletronuclear – Eletrobras Termonuclear S. A.; Brazilian Company of Holdings in Nuclear and Binational Energy (ENBPar); Brazilian Army; Nuclear Industries of Brazil (INB); Brazilian Institute of Environment and Renewable Natural Resources (IBAMA); Institute for Energy and Nuclear Research (IPEN); Ministry of Mines and Energy (MME)). Are Brazilian authorities transparent regarding nuclear energy? Are Brazilian nuclear power plants safe? Is the population sufficiently informed about the Brazilian nuclear energy sector? Is information about the legislation applicable to nuclear risks accessible? Would you change your mind about the Brazilian nuclear energy sector if you had more knowledge on the subject? Do you know of any laws related to nuclear energy in Brazil? How is nuclear waste managed in Brazil? If you lived near a waste storage facility, would you consider the risk to be greater if you lived near: Chemical waste, Radioactive waste, Industrial waste, or Household waste.



b) Knowledge about Radioactivity

Are you exposed to radioactivity in your daily life? What can be the origin of radioactivity? If radioactivity is of natural origin, is it dangerous? If yes, classify it on a scale: Slightly dangerous, Quite dangerous, Dangerous, or Very dangerous. If radioactivity is of artificial origin, is it dangerous? If yes, classify it on the same scale. In your daily environment, which radioactivity poses the greatest danger? To which areas do you associate radioactivity? To which of these scientific terms is radioactivity associated? (Ionizing radiation, Atom, Energy, Fusion/fission, Radionuclides). Which chemical elements are associated with radioactivity? What is the distance to the nearest Brazilian nuclear power plant? Is there a systematic association between radioactivity and cancer risk? If not, do you believe it is a matter of dose? What can be affected by radioactivity? (Thyroid gland, Bones, Lungs, Skin, Eyes, Blood, I don't know). How can radioactivity affect you? Do you know how to protect yourself from radioactivity in case of an accident?

c) Behavior about Nuclear Energy

In which sources of information would you trust in case of a nuclear alert (Social media, TV, Radio, The nuclear industry, A government agency)? Do you know the warning signal for a nuclear accident? In case of a nuclear alert, what would you do (Move to a confined space, Block air vents, Prepare for a possible evacuation, Seek iodine, I don't know)? What would be your state of mind? If you had more knowledge about the nuclear sector, would you change your mind about nuclear energy? Are you over or under 25 years old? What is your field of study? What is your suggestion for the questionnaire?

2.. Data Analysis Plan

After collecting the data through the online questionnaire, the analysis will be conducted in a structured manner across four complementary phases, aiming to extract the maximum amount of information and validate the comparisons between the sample subgroups (professors, students, and technicians) .

2.2.1. Phase 1: Pre-Analysis and Descriptive Analysis

This initial phase consists of organizing and summarizing the raw data to understand the general overview of the responses. The following procedures will be carried out:

- Verification of incomplete responses;
- Generation of tables and charts to visualize the percentage distribution of responses for each question;
- Calculation of Measures of Central Tendency, such as mean, median, and mode.

2.2.2. Phase 2: Quantitative Inferential Analysis

In this phase, the idea is to compare the groups to identify if the observed differences are statistically significant. The following statistical tests will be employed to verify correlations and discrepancies among the groups regarding nuclear energy (Helene , Vanin, 1991):

- **Chi-Square Test (χ^2):** This will be used to test the association between categorical variables. For example, to verify if there is a statistically significant relationship between the "respondent's group" (professor, student, technician) and the perception of the safety of Brazilian nuclear power plants.
- **Analysis of Variance (ANOVA) or Kruskal-Wallis Test:** To compare the mean responses on a scale among the four sample groups. If ANOVA indicates a significant difference, post-hoc tests (such as Tukey's Test) will be applied to precisely identify which pairs of groups differ from each other (for example: professors versus students).

2.2.3. Phase 3: Qualitative Analysis



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For the single open-ended question on the form, the suggestions and comments will be categorized to identify recurring themes, such as suggestions for new questions, critiques of the questionnaire's structure, or thematic elaborations, offering insights for the improvement of the instrument and for understanding the respondents' perspectives.

2.2.4. Phase 4: Integrated Analysis

In this phase, the data on perception, knowledge, and behavior will be integrated to test the central hypotheses of the study. The analysis will correlate variables from different sections of the questionnaire—such as cross-referencing the level of technical knowledge with the degree of trust in the nuclear industry—to build an explanatory model that demonstrates how these three pillars interact to shape opinion on nuclear energy within the surveyed community.

3 RESULTS AND DISCUSSIONS

Although data collection has not yet begun, the structure of the questionnaire and the analysis plan allow for the anticipation of the potential for discussion that the future results will generate. The analysis will be based on the comparison between the sample subgroups (professors, students, and technicians from UFABC) and, at specific moments, with the findings of Perez et al. (2020). The discussion will be organized around the three axes of the questionnaire:

- a) Risk Perception: It is expected that the comparative analysis will reveal differences in risk perception associated with the respondents' level of education and field of work. Questions like "Does the nuclear industry scare you?" and "Are Brazilian nuclear power plants safe?" will allow for the quantification of this perception. The discussion of these results will be contrasted with the theoretical framework on perceived risk versus actual risk, investigating whether, in the UFABC sample, this disparity aligns with the findings in international literature. It will be possible to debate whether greater technical knowledge, presumably present in professors and technicians, correlates with a lower perception of risk.
- b) Knowledge about Radioactivity: In this section, it will be possible to profile the technical knowledge level of the sample. The central hypothesis to be discussed is whether factual knowledge about radioactivity (its origins, associated elements, etc.) directly influences the responses on risk perception. For example, do respondents who know they are exposed to natural radioactivity in their daily lives show less fear of the nuclear industry? The discussion will delve into the relationship between knowledge, information, and perception, a central point in the work of Stoutenboroug et al. (2013).
- c) Behavior towards Nuclear Energy: This axis will allow for a discussion on trust and decision-making in hypothetical crisis scenarios. The analysis of the question about reliable sources of information in case of a nuclear alert may indicate the academic community's level of trust in state institutions and the industry itself. The comparison of the results from UFABC students with those from the French university (UCA) will be particularly rich on this point, allowing for a debate on how the context of a country with a consolidated nuclear matrix (France) and a country with modest participation (Brazil) can shape behavior and perceived trust.

Ultimately, the integrated discussion of the results will provide a precise diagnosis of the main doubts and fears about nuclear energy in the surveyed community. This diagnosis will serve as a basis for the subsequent stage of the project: the planning of scientific dissemination and extension actions. Such actions will be designed to mitigate the identified knowledge gaps and



specific fears, thereby seeking to broaden the social acceptance of nuclear energy based on a more qualified and informed public debate.

4 CONCLUSIONS

This article presented a methodological preparation for a study on risk perception, knowledge, and behavior towards nuclear energy in a Brazilian university community. The adaptation of an internationally validated questionnaire and the definition of a robust data analysis plan, which blends quantitative and qualitative approaches, show the potential for generating relevant results in the national context. The analysis of these results will also be guided by a comparative approach, in which, for example, the UFABC student subgroup will be compared to the results of the UCA student group (Perez et al., 2020).

The selected theoretical framework will provide scientific support for the analysis of the data generated by the interview and will be used in the comparison phase. From the literature on these perceptions of risk, knowledge, and behavior towards nuclear energy, which seeks to understand the researched situations, four specific aspects were selected: 1) Perceived risk by the public versus actual risk, according to experts (Brenot et al., 1996); 2) The perceived risk of nuclear energy in the United States (Slovic et al., 2004); 3) Research on nuclear risks in 16 countries and associated opposition to nuclear energy: waste, civil security, destruction of landscapes, high costs, climate change (IPSOS GLOBAL ADVISOR, 2015); 4) The observed differences regarding nuclear risks among various social groups (Stoutenboroug et al., 2013).

The theoretical framework will help to understand why, according to the literature, people in countries where nuclear energy is established perceive nuclear risks as lower than their peers in countries with no nuclear power plant installations, and it will also aid in understanding the relationship between the legislation adopted in each country and international organizations (OECD, 2010).

In summary, based on this presented theoretical and methodological framework, the present research, once completed, will function as a diagnostic tool, and its results will provide the necessary basis for the creation of an action plan for scientific dissemination and extension, focused on mitigating the fears and knowledge gaps that are identified. Thus, the study contributes directly to building a more solid foundation for the public acceptance of nuclear energy in Brazil, enhancing the quality of the dialogue between experts, government, and society about the future of the sector, especially in the context of the introduction of new technologies like MMRs.

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