

Stakeholder Engagement In The Adoption Of Nuclear Propulsion In Merchant Shipping

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ABSTRACT

The successful attainment of the EU's 2030 Climate Target Plan necessitates substantial reductions in carbon dioxide emissions from international maritime transport. Moreover, the International Maritime Organization has adopted a strategy aimed at achieving net-zero greenhouse gas emissions from international shipping by 2050. These objectives entail both a reduction in energy consumption through enhanced energy efficiency and a transition towards cleaner types of energy, including renewable energy and low-carbon fuels.

Nuclear propulsion in merchant shipping represents a novel and potentially transformative technology with the capacity to substantially reduce greenhouse gas emissions from international maritime transport. It enables long operational intervals without refuelling and can support either higher transit speeds or increased cargo capacity, depending on the priorities of the shipping companies. At the same time, the technology introduces a distinct set of challenges, which are examined in this study through a comprehensive PESTLE analysis. Although the technical and regulatory challenges are substantial, the societal dimension plays an especially critical role.

As highlighted by the International Atomic Energy Agency, stakeholder engagement is a vital element of nuclear projects. Unlike land-based nuclear facilities, where stakeholders are typically fixed, nuclear propulsion in merchant shipping involves a dynamic stakeholder landscape, as vessels move between ports and jurisdictions. These stakeholders must therefore be identified and engaged. Understanding stakeholder perspectives, particularly those of crew members, is essential for the responsible and successful implementation of nuclear-powered merchant shipping. Although nuclear propulsion in merchant shipping is a novel application, apart from a few merchant ships in the past, concerns stemming from past nuclear incidents remain and must be addressed.

This study identifies the key stakeholders in nuclear-powered merchant shipping, with a particular focus on the maritime workforce. It examines the level of acceptance of nuclear-powered vessels, as well as the safeguards and operational conditions they deem necessary for considering employment aboard such ships.

The significance of this research lies in its contribution to an emerging and underexplored area of maritime innovation – nuclear propulsion in merchant shipping – by identifying the prerequisites for successful implementation and addressing a critical human factor: crew acceptance.

Keywords: *Maritime nuclear power, stakeholder engagement, nuclear corridor, crew acceptance*

1 INTRODUCTION

The EU's 2030 Climate Target Plan, specifically through the FuelEU Maritime Regulation and the EU Emissions Trading System (ETS), mandates a transition to decarbonize maritime transport. Achieving significant reductions in carbon dioxide emissions of international maritime transport requires both enhanced energy efficiency and a transition towards cleaner types of energy, including renewable energy and low-carbon fuels. The European Union's Communication on the 2030 Climate Target Plan 3, COM (2021) 562, explains that the necessary technology development and deployment must happen already by 2030 to prepare for a much more rapid change thereafter [1]. Furthermore, the 2023 strategy of the International Maritime Organization (IMO) aims to achieve net-zero greenhouse gas (GHG) emissions from international shipping by or around 2050 [2].

1.1 The case for nuclear propulsion

Global shipping, handling more than 80% of global trade [3], is responsible for approximately 3% of global greenhouse gas (GHG) emissions. In response to the imperative for decarbonization of shipping, several projects aiming to develop low-carbon fuels have been developed. However, the shipping industry and other floating assets at sea consumes almost 400 million tonnes of various fossil fuels. Replacing this with green alternative fuels will require vast amounts of electricity (more than 10,000 TWh/year) [4]. Thus, as of today, global shipping is likely to stay fossil fuelled unless nuclear propulsion is being developed. Nuclear propulsion in merchant shipping is therefore a new and potentially transformative technology that may contribute significantly to the reduction of GHG from international maritime transport.

Nuclear propulsion provides the capability for substantially extended operational durations without refuelling and offers the potential for either enhanced transit speeds or increased vessel capacity, whichever is preferred by the shipping companies. Due to the extreme energy density of nuclear fuel, this allows the ships to operate for decades without needing new fuel. The vessels need only suspend operations for periodic inspections every five years as part of the classification process [5].

Nonetheless, the adoption of nuclear propulsion is accompanied by a range of technical, regulatory and socio-economic challenges. A recent study from the NuProShip project indicates that advanced reactor concepts based on Generation IV (Gen-IV) small modular reactors (SMR) technologies have the potential to enable commercially viable, zero-emission shipping while delivering exceptionally high levels of operational safety and nuclear fuel security [6]. However, several technical issues remain to be resolved before the first nuclear-powered merchant vessel can become operational.

In addition, one of the most complex challenges arises from the inherently international nature of merchant shipping. Nuclear-powered vessels will operate across multiple jurisdictions engaging with numerous port states throughout their voyages. As vessels transit across international waters and call at ports under different national jurisdictions, the network of authorities, regulatory bodies and local communities involved shifts continuously. This mobility creates unique challenges for regulatory harmonisation, safety oversight, emergency preparedness, and public acceptance, as responsibility must be coordinated across multiple and often diverse legal and institutional frameworks.

In contrast to land-based nuclear facilities, where the constellation of stakeholders is relatively stable and geographically bounded, the use of nuclear propulsion in merchant shipping introduces a far more fluid and complex stakeholder environment. Understanding stakeholder perspectives at large is therefore essential for its responsible and successful implementation. Stakeholder engagement is recognised as a critical component of nuclear projects, as emphasized by the International Atomic Energy Agency (IAEA). Although the application of nuclear propulsion in merchant shipping remains comparatively novel, concerns persist, influenced in part by the legacy

of historical nuclear incidents [7]. Addressing these concerns is therefore essential to establish confidence among regulators, industry stakeholders, and the wider public, and is particularly critical for those stakeholders who will be directly affected, such as crew members.

1.2 Stakeholder engagement

According to Covello [8], a stakeholder can be defined as any actor – institution, group or individual - with a vested interest, or stake, in the decision-making and activities of a business, organization or project. The International Atomic Energy Agency (IAEA) defines stakeholders broadly as ‘any group or individual who feels affected by an activity, whether physically or emotionally’, and distinguishes between ‘statutory stakeholders’, who are required by law to be involved in a nuclear project, and ‘non-statutory stakeholders’, who have an interest in the project or will be directly or indirectly impacted [9]. According to Clarkson [10], a primary stakeholder group is one ‘without whose continuing participation the corporation cannot survive as a going concern’, while the secondary stakeholder groups are defined as ‘those who influence or affect, or are influenced or affected by, the corporation, but they are not engaged in transactions with the corporation and are not essential for its survival’. Clarkson’s distinction between primary and secondary stakeholders is particularly useful when identifying stakeholders of nuclear-powered merchant shipping, as it requires consideration of actors at all levels – from governmental authorities to the general public. Hence, this definition will be used in the present study.

Stakeholders come with a variety of perspectives, interests and values regarding safety, environmental impacts, legal framework, or economic costs and benefits [11], and key stakeholders can have the power to support or hinder the development of the project based on their prediction of the outcome as risky or beneficial [12]. The systematic process in which the stakeholders are included in the organization’s activities by having their needs and values listened to, acknowledged, and integrated in the decision-making process, is called ‘stakeholder engagement’ [8].

According to IAEA [9], the key principles of stakeholder engagement in relation to nuclear energy are (1) Build trust, (2) Demonstrate accountability, (3) Exhibit openness and transparency, (4) Practice early and frequent consultation, (5) Communicate benefits and risks. The objective of stakeholder engagement is to ensure that all relevant parties are afforded the opportunity to express their perspectives, and that these perspectives are duly considered within the decision-making process. The intention is not necessarily to reach consensus among stakeholders, but rather to facilitate a shared understanding of the rationale underpinning decisions, thereby fostering trust in the appropriateness of the outcome.

Decades of research have demonstrated the critical importance of stakeholder engagement in nuclear projects [9]. Studies consistently show that when the public is able to participate in decision-making processes and has accessible channels for voicing concerns and opinions, acceptance of nuclear energy development increases [13]. Such participation enhances trust in institutions and reduces perceived risks, indirectly strengthening public support. Acceptance is further influenced by perceived benefits [14], and by higher levels of public knowledge and understanding of nuclear technologies [15]. Perceived risks, however, remain strongly linked to environmental, health and safety concerns, with fear of nuclear accidents acting as a major deterrent [16]. High-profile incidents, such as the Fukushima Daiichi disaster in Japan, have significantly shaped public perceptions of risk [17, 18].

Studies indicate that certain factors influence the acceptance of nuclear energy more strongly than others. Socio-economic factors may play a role in shaping attitudes towards nuclear energy [19], often by influencing perceptions of risk and benefit. Gender appears to be a relevant factor, as women tend to exhibit a higher risk perception regarding nuclear technology [20-22], whereas age seems to be a poor predictor of support for nuclear power [23, 24]. Education can further affect attitudes; individuals with limited exposure to science and technology often display more risk-averse views, whereas those with greater knowledge tend to hold more favourable opinions [25, 26]. This aligns with research showing that scientists perceive nuclear energy as significantly less

risky than laypeople [27]. Nevertheless, the impact of education is strongly mediated by personal beliefs and pre-existing convictions [26].

In summary, multiple factors influence perceptions of nuclear energy. Strengthening dialogue and enabling public participation is therefore essential for securing societal support and enhancing social acceptability. When the stakeholder dialogue breaks down, stakeholders may become opponents. Research finds that conflicting groups intensify strategizing in response to failed engagement, leaving little room for resuming meaningful involvement [28].

The general literature on stakeholder engagement is extensive; however, research that specifically examines stakeholder engagement in the context of nuclear-powered shipping remains limited, and in some areas entirely absent. This study addresses this gap by investigating stakeholder engagement within the domain of nuclear-powered merchant shipping, drawing upon the broader body of stakeholder engagement scholarship as well as the core principles outlined by the IAEA.

The primary objective of this study is to identify the key stakeholder groups relevant to the deployment of nuclear propulsion in merchant shipping, with particular emphasis on the maritime workforce. The ship's crew constitutes a critical stakeholder group, as their acceptance is indispensable to the practical and operational realisation of nuclear propulsion at sea. It is therefore essential to understand which safeguards, working conditions, and operational assurances crew members consider necessary for employment on a nuclear-powered vessel to be regarded as acceptable and desirable, as well as to assess their overall willingness to undertake such roles. By identifying the prerequisites for successful implementation and addressing the central human factor of crew acceptance, the study provides insight into one of the key determinants of whether nuclear propulsion can be viably integrated into the future commercial fleet.

The significance of this research lies in its contribution to an emerging and underexplored area of maritime innovation – namely the introduction of nuclear propulsion in merchant shipping.

2 METHODS

A descriptive, cross-sectional study was conducted in September and October 2025. The questionnaire was administered in Norwegian and English language and was open for 30 days. The resultant 497 respondents were recruited through 11 ship owners. Participation was voluntary, and respondents were informed that survey responses would be used for research purposes. Completion and submission of the questionnaire implied consent. No questions were mandatory; respondents could exit the survey at any time. Data collections were handled using a secure survey platform developed and hosted by the University of Oslo (nettskjema@usit.uio.no). Participant anonymity and data confidentiality were ensured by excluding identifying information and using the Nettskjema system. Cross-sectional studies have well-known weaknesses and strengths, but such studies are useful for establishing preliminary evidence in planning a future advanced study [29]. However, the purpose of this initial study is to understand crew members attitudes towards nuclear propulsion, as a snapshot, and for this purpose cross-sectional studies are well-suited.

The data obtained from the survey were analysed using Microsoft 365 Excel, version 2306 and SPSS, version 31. Results presented as percentages were based on the number of completed values for each variable. The chi-square test was used to assess associations between categorical, binary variables. Statistical significance was set at 0.05 for all analyses.

The PESTLE-analysis was developed based on previous publications [30-34] and own conclusions (NuProShip II project).

3 RESULTS

The stakeholder groups involved in nuclear-powered merchant shipping differ markedly from those associated with land-based nuclear power plants. It is therefore necessary to undertake a

systematic identification and categorisation of these actors. Mapping the opportunities and challenges linked to the adoption of nuclear propulsion in merchant shipping through a Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) analysis enables a clearer understanding of stakeholder roles and the barriers that must be addressed to ensure successful implementation. Given that the ship's crew represents one of the most critical stakeholder groups, this study also examines crew members' attitudes towards employment on board nuclear-powered vessels.

3.1 Stakeholders, opportunities and challenges in nuclear-powered merchant shipping

The key stakeholder groups relevant to nuclear-powered merchant shipping were identified and classified as primary or secondary stakeholders, as illustrated in Figure 1. Primary stakeholders are those directly involved in decision-making, safety oversight and operational activities; consequently, the success of nuclear-powered shipping is contingent upon their involvement, approval and sustained cooperation. All stakeholders identified as primary in Figure 1 are essential participants whose authorisation and collaboration are prerequisites for development and implementation of nuclear-powered shipping.

In contrast, secondary stakeholders are not directly involved in or immediately affected by the project, yet they retain significant capacity to influence its trajectory. Although their involvement is less direct, their perceptions, regulatory expectations, and socio-political influence can substantially shape the enabling environment for nuclear-powered shipping, affecting matters such as port access public legitimacy, and financing conditions (Figure 1). The identified stakeholder groups may hold divergent priorities, concerns, and expectations, a comprehensive understanding of their perspectives is therefore fundamental to ensuring the responsible and effective development of nuclear-powered merchant shipping.

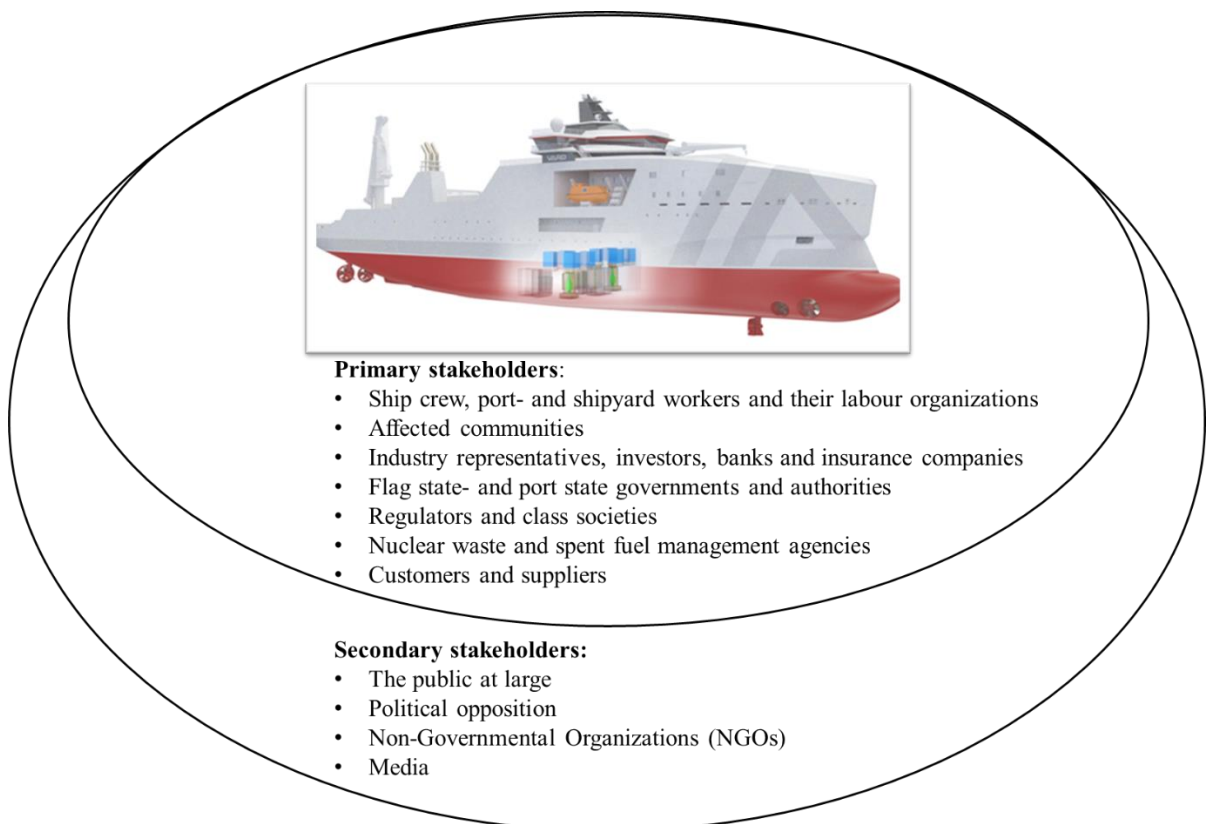


Figure 1: The primary and secondary stakeholders in nuclear-powered merchant shipping. The ship in the centre is a rendering used with kind permissions from Vard Design AS.

A PESTLE analysis was employed to identify the key prerequisites for the successful implementation of nuclear-powered merchant shipping (Table 1). Mapping the principal challenges and opportunities associated with regulatory development, technological advancement, funding mechanisms, environmental considerations, and societal acceptance of nuclear energy provides a foundation for informed strategic planning. Such an analysis also supports the mitigation of risks by highlighting the external factors that must be addressed to enable the safe, viable, and publicly acceptable deployment of nuclear propulsion in the commercial fleet.

The *political* and *legal* dimensions of the PESTLE analysis indicate that implementing nuclear-powered shipping will require political commitment to adapt existing regulatory frameworks. Nuclear-powered vessels will operate across multiple jurisdictions and port states, each with distinct regulations and liability regimes. To enable global operations, such vessels will necessitate the establishment of so-called *nuclear corridors*, defined by bilateral or multilateral port-entry agreements between flag states and port states. Within these corridors, ships may operate under contractual agreements between governments, which must also reconcile differences in national nuclear regulations. The objective of such agreements is to limit potential insurance claims and provide indemnification mechanisms for insurers.

In parallel, regulatory and procedural frameworks governing the implementation of nuclear propulsion must be developed or updated. Nuclear-powered vessels will be required to comply with several regulatory layers: IMO's safety standards; IAEA's nuclear safety and security principles; flag-state and port-state nuclear regulations; insurance industry requirements for commercial cover; and classification society rules specific to nuclear propulsion.

The international legal basis for nuclear-powered merchant shipping is set out in the International Convention for the Safety of Life at Sea (SOLAS), which has included a dedicated chapter on nuclear ship since 1974. This chapter incorporates the IMO's 1980 *Code of Safety for Nuclear Merchant ships*, a detailed design and operational framework based on 1970s pressurised-water reactor technology. Although never formally ratified, the Code was adopted as a recommendation that IMO states could integrate into national legislation. In light of renewed global interest in nuclear-powered merchant shipping, the IMO has recently initiated work to update the Code to reflect contemporary needs, including advanced reactor designs. Established in 2025, the *Atomic Technology Licensed for Application at Sea* (ATLAS) initiative represents a joint effort by the IAEA and the IMO to develop a comprehensive regulatory framework for the safe, secure, and peaceful deployment of nuclear propulsion and floating nuclear power plants in maritime contexts.

The *economic* and *technological dimensions* of the PESTLE analysis indicate that substantial upfront investment is required for the development of Gen-IV reactors incorporating passive safety features suitable for maritime applications, alongside advanced digital monitoring systems, robust cybersecurity measures, and proliferation-resistant design. Significant investment is also required for the handling of nuclear-grade materials, including fuel, spent fuel, and radioactive waste. In parallel, specialized insurance and reinsurance schemes must be established, supported by clear liability and indemnity frameworks capable of addressing risks such as collision or grounding. Additional expenditure will raise from training crew members and certifying nuclear-qualified operators. However, long-term operational costs are expected to remain stable and competitive, and the higher operating speed of nuclear-powered vessels may enable more efficient logistics and, consequently, more effective capital deployment. Nevertheless, investors and financial institutions may be reluctant to support nuclear-powered shipping due to perceived political, regulatory, and reputational risk, thereby creating further barriers to commercial adoption. These potential risks must therefore be systematically addressed through robust mitigation strategies focused on environmental considerations and stakeholders' perception of nuclear-related risks, in addition to the challenges outlined above.

Table 1: A PESTLE-analysis of the implementation of nuclear-powered merchant shipping

	Opportunities	Challenges
Political	<ul style="list-style-type: none"> • Potential for strategic energy independence and reduced reliance on fossil fuel supply chains. • Strong alignment with national- and international climate goals, including IMO’s target of net-zero emissions by 2050. • Growing political interest in nuclear propulsion in key maritime nations, IMO and IAEA. 	<ul style="list-style-type: none"> • Political opposition at local- and national levels due to safety, waste, and environmental concerns, affecting port states and flag states. • Political and regulatory frameworks reflecting pressurized-water reactor technology and approaches on land, creating policy implementation challenges. • Nuclear-powered ships require multilateral port-entry agreements to operate globally or international regulations via IMO, IAEA and others. • Insurance and reinsurance challenges, requiring predictable indemnification from governments to achieve commercial viability.
Economic	<ul style="list-style-type: none"> • Nuclear propulsion could significantly reduce fuel costs due to high energy density and long fuel cycles. • Potential for higher speed enabling more efficient and competitive logistics chain as well as more effective capital deployment. • Long-term economic stability due to less exposure to volatile fossil fuel markets. • Waste management is fundable through predictable ownership regimes. • Customers and suppliers prefer low-carbon logistics. 	<ul style="list-style-type: none"> • Potentially high up-front capital expenditure, specialized construction, and nuclear grade materials increase financial risks and may require additional financing. • Specialized crew and training costs for nuclear-qualified operators increase lifecycle costs. • Investors and banks may hesitate due to perceived political, regulatory, and reputational risks. • Cost and siting challenges for spent nuclear fuel and to some extent nuclear waste.
Social	<ul style="list-style-type: none"> • Potential for long-term high-skilled job creation in nuclear engineering, advanced manufacturing, radiation safety, and emergency preparedness. • Could strengthen public perceptions of shipping as a leader in climate solutions. 	<ul style="list-style-type: none"> • Concerns about radiation, nuclear safety, and waste, affecting acceptance in both port- and yard communities, among workers and labour organizations. • Fear-driven media coverage can influence public and political opposition.
Technological	<ul style="list-style-type: none"> • Advances in Small Modular Reactors (SMRs), digitalization, automation, and standardized Gen-IV reactor designs improve safety and reduce costs. • The ATLAS initiative supports IMO in revising outdated regulations needed for deploying nuclear propulsion in merchant shipping. • Ability to operate zero-emission floating power stations, enabling significant operational flexibility and speed improvements. • Potential innovation spillovers into the wider maritime sector (cybersecurity, advanced materials, remote monitoring, new ship designs, and marine reactors). • Industrialization of maritime nuclear reactors can positively influence land-based nuclear industry. 	<ul style="list-style-type: none"> • Existing IMO safety codes are based on pressurized-water technology and require revision to accommodate advanced reactor designs. • The use of Gen-IV reactors requires licencing of novel design, the demonstration of passive safety, and fuel qualification. • Integration of nuclear systems in shipyards requires new infrastructure, qualification, and supply chain capabilities. • Risks of technology theft or nuclear proliferation, requiring strong safeguards and security systems. • NGOs and environmental groups may oppose the technology due to perceived risks.
Legal	<ul style="list-style-type: none"> • Ongoing international efforts to harmonize nuclear- and maritime regulations, especially involving IMO and IAEA frameworks, strengthen future legal and regulatory predictability. • Development of modernized, technology-neutral standards by regulators and class-societies could streamline reactor licensing and port-entry procedure. • The first ships can operate in defined nuclear corridors with a contractual approach. 	<ul style="list-style-type: none"> • Complex legal landscape consisting of nuclear law and maritime law that has never been combined before. • Nuclear liability, indemnification, and nuclear spent fuel regulation differ across jurisdictions – raising barriers for international voyages. • Port-state authorities may impose restrictive entry conditions or deny entry entirely due to unresolved legal- or safety requirements, or also public perceptions of risk.
Environmental	<ul style="list-style-type: none"> • Nuclear propulsion offers a deep decarbonization pathway with almost zero operational greenhouse gas emissions. • Virtually complete elimination of SOx, NOx, and particulate emissions; and reduced ocean pollution from conventional fuels. • Lower fuel-transport risk compared to fossil fuels bunkering. 	<ul style="list-style-type: none"> • Long-term management of nuclear waste requires robust institutional frameworks, public oversight, and international safeguards. • Potential environmental concerns from accidental release scenarios, shipyard-handling of radioactive material, and end-of-life reactor disposal.

Opposition may arise at both local and national levels, driven by concerns relating to safety, radioactive waste-management, and potential environmental impacts. Such concerns may influence levels of acceptance in both port and flag states. The *Environmental* dimension of the PESTLE analysis indicates that end-to-end fuel-cycle and waste-management plans must be developed and integrated with port and shipyard procedures, alongside emergency-response procedures and compliance with internationally recognised decommissioning frameworks. Engagement with environmental NGOs is essential, and strategies for nuclear waste-management should be established and clearly communicated to the public.

The *Social* dimension of the analysis underscores the need for sustained and meaningful stakeholder engagement. Perceived health risks among ship crews, port- and shipyard workers, and communities located near maritime infrastructure may weaken support within labour organisations, local populations, and the broader workforce. Such concerns have the potential to undermine the legitimacy, feasibility and ultimately the successful implementation of nuclear-powered shipping. Developing workforce competence in nuclear-safety and emergency response, supported by targeted training and information seminars, is therefore vital. Transparent communication of both risks and benefits, together with sustained dialogue with affected port- and shipyard communities, is critical for building trust. Broader public engagement, including proactive interactions with the media and potential opponents, should also be prioritised.

Shipyards responsible for reactor installation, maintenance and periodic inspections, as well as port facilities that host or service the vessel, play a central role in ensuring that nuclear operations are carried out safely, transparently, and in accordance with regulatory standards. Early and open engagement with local communities and labour organizations can help address concerns before they escalate.

In summary, the challenges identified through the PESTLE analysis must be effectively addressed to realise the advantages of energy independence, reduced reliance on fossil fuels, and lower greenhouse gas emissions. Crew members are identified as one of the most critical stakeholder groups; the remainder of this study therefore focuses on their attitudes towards employment on board nuclear-powered vessels.

3.2 Attitudes towards employment on board nuclear-powered vessels

Crew members' attitudes towards employment on board nuclear-powered vessels were examined using survey data from 497 participants representing several maritime occupational categories. The survey results show that the majority of respondents were male, with only 4% identifying as female (see Table 2). All age groups were represented, although most participants were between 19 and 49 years of age. Most respondents held either vocational qualifications or a bachelor's degree. In terms of nationality, 65% were Eastern or Western European and 32% were Filipino. Engineers, chief engineers and captains were among the most frequently represented occupational groups in the sample (Table 2).

Public knowledge of nuclear energy appears to vary considerably. However, 79% of respondents reported being familiar with both the potential benefits and the associated risks of nuclear energy. An even larger proportion (94%) expressed interest in learning more about nuclear energy and the operation of nuclear-powered ships. This suggests a strong willingness among participants to expand their knowledge, including those who already consider themselves reasonably well-informed.

Table 2: Demographics features of the respondents (N=497)

Demographic features	N	% of total
Gender		
Male	475	95,6
Female	22	4,4
Age		
19-29 years	126	25,4
30-39 years	142	28,6
40-49 years	121	24,3
50-59 years	82	16,5
60 years or older	26	5,2
Education		
Primary education	2	0,4
Secondary education / high school	65	13,1
Vocational School/College	124	24,9
Bachelor's Degree	203	40,8
Master's Degree	87	17,5
Doctoral Degree / PhD	2	0,4
Other	14	2,8
Occupation		
Captain / Master	70	14,1
Chief Mate	37	7,4
Mate	48	9,7
Chief Engineer	75	15,1
Engineer	79	15,9
Cadet	15	3,0
Able-Bodied Seaman	28	5,6
Motorman	16	3,2
Chief Steward/Steward	19	3,8
Electrician	18	3,6
Student in Nautical Sciences	38	7,6
Other	54	10,9
Nationality		
Norwegian	192	38,6
Eastern European	47	9,5
Western European	82	16,5
Filipino	161	32,4
Asian	1	0,2
African	3	0,6
Other	11	2,2

To assess whether respondents viewed nuclear power as a viable alternative fuel for ships, they were asked to identify which fuel types they believed would dominate the maritime sector by 2050. More than 60% of respondents selected liquefied natural gas (LNG), while nuclear energy was the second most frequent choice (51%), as shown in Figure 2. Marine diesel oil (MDO) or marine gas oil (MGO) ranked third. Only 12% of respondents believed that heavy fuel oil (HFO), which currently is the dominant global marine fuel, would remain predominant by 2050. These responses indicate that a substantial share of participants view nuclear propulsion as likely to play an important role in the future fuel landscape of commercial shipping.

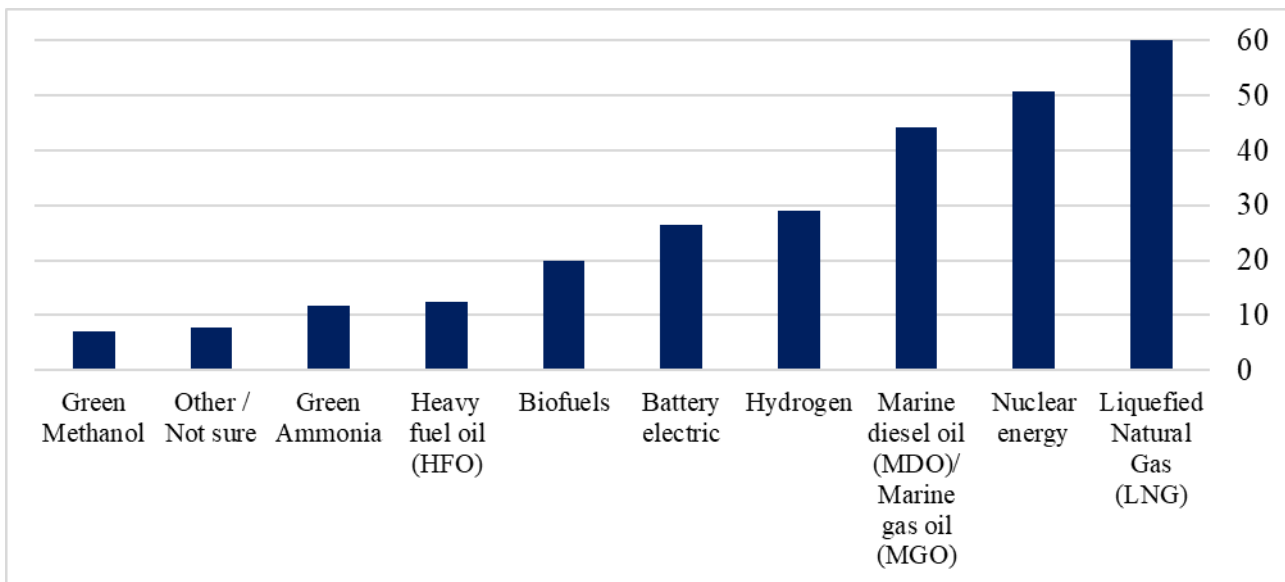


Figure 2: The proposed fuel types expected to dominate the shipping sector by 2050

Respondents were asked whether they would be willing to work on board a nuclear-powered vessel. The results indicated that the majority (65%) expressed a positive inclination, while 27% reported being uncertain. Only 8% of respondents stated that they would not consider working on board a nuclear-powered vessel.

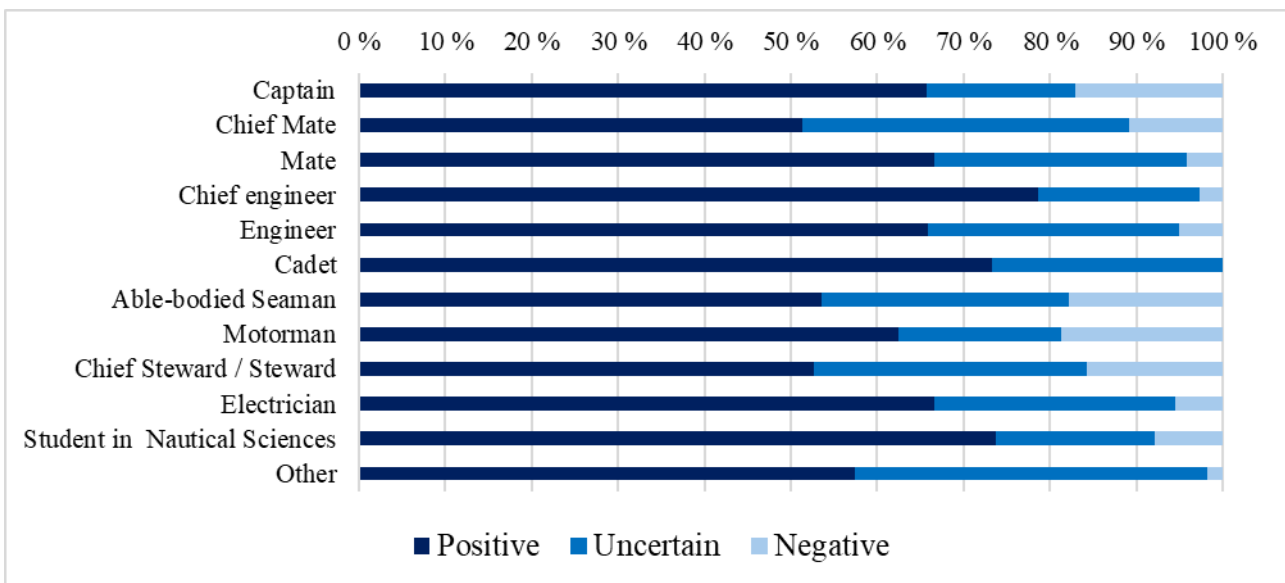


Figure 3: Occupational differences in attitudes towards employment on board nuclear-powered vessels (N=497, presented as % of for each occupation category)

The occupational groups most positive towards working onboard a nuclear-powered vessel were chief engineers, followed by cadets and students (Figure 3). A chi-square test revealed that chief engineers had significantly more positive attitudes towards working on board nuclear-powered vessels when compared to the rest of the respondents (79% versus 63 %; Chi-square: $\chi^2 (1, N = 497) = 6,977, p = 0,009$). Notably, captains were disproportionately represented among those who indicated unwillingness to work on board a nuclear-powered ship. Nevertheless, 66% of captains expressed positive attitudes towards such employment (Figure 3).

Respondents were distributed across age groups (Table 2). The share of respondents in each age group who reported a positive attitude toward working on board a nuclear-powered vessel ranged from 54% to 74%. Employees in the age group 30-39 years old were found to have significantly less positive attitudes towards working on board nuclear-powered vessels when compared to the other age groups (54% versus 70 %; Chi-square: $\chi^2 (1, N = 497) = 10,954, p = 0,001$), see Figure 4.

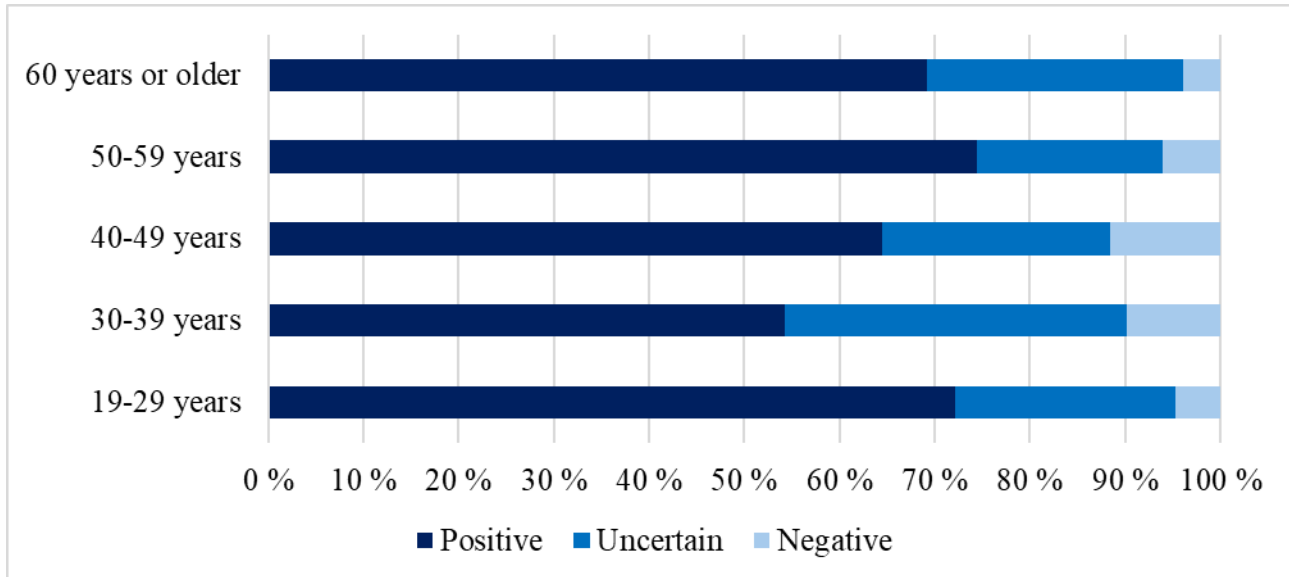


Figure 4: Variations in attitudes towards employment on board nuclear-powered vessels by age group (N=497, presented as % of total for each category)

Furthermore, the results indicated that female respondents were significantly less positive than their male counterparts about working on board a nuclear-powered vessel (36% versus 67%; chi-square: $\chi^2 (1, N = 497) = 8,571, p = 0,003$), see Figure 5. It should be noted that only 22 female respondents versus 475 male respondents participated in the study, and that 50% of the female respondents responded that they were uncertain. Conversely, no significant difference was observed between respondents with or without children, regarding their willingness to work on board such vessels (66% versus 64%; $\chi^2 (1, N = 497) = 0,3630, p = 0,5469$).

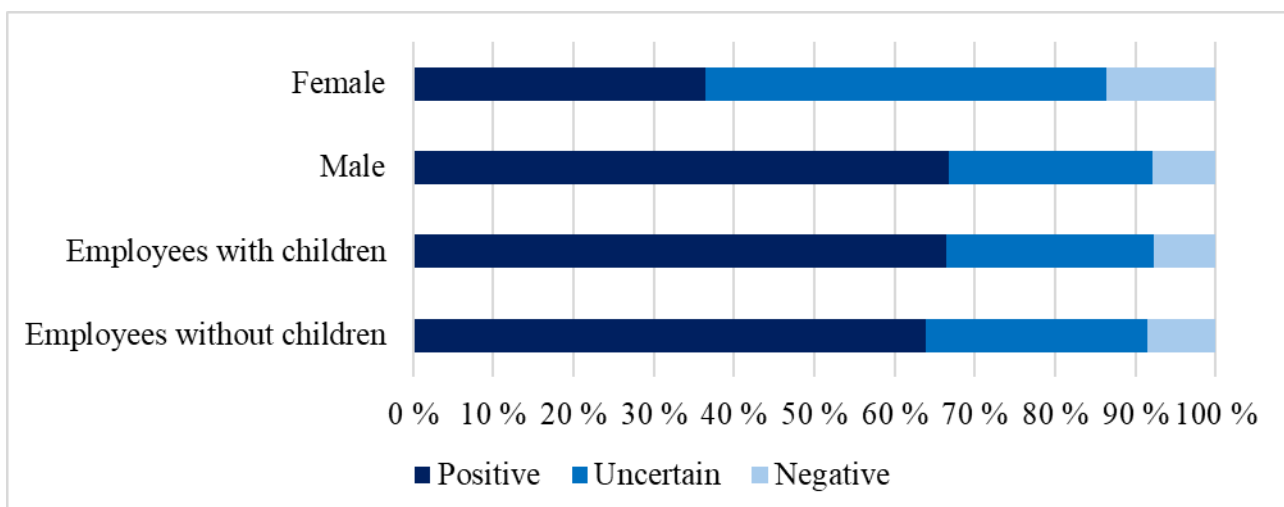


Figure 5: Variations in attitudes towards employment on board nuclear-powered vessels among females and males, and employees with children and those without children (N_{male}=475, N_{female}=22, N_{children}=298, N_{NoChildren}=199; presented as % of total for each category)

Regarding nationality, the results indicated that Norwegian crew were significantly more positive than crew of other nationalities about working on board a nuclear-powered vessel (77% versus 58%; chi-square: $\chi^2(1, N = 497) = 17,249, p < 0,001$). Filipino crew were, however, significantly less positive when compared to crew of other nationalities about working on board a nuclear-powered vessel (57% versus 70%; chi-square: $\chi^2(1, N = 497) = 8,280, p = 0,005$).

3.3 Safeguards and operational conditions considered necessary

Respondents were asked to select the five most important technical design features and operational safeguards that would be required for them to consider employment on board a nuclear-powered vessel. As shown in Table 3, the safeguards considered to be most important were comprehensive training for all crew members in nuclear safety and emergency response, followed by training with an advanced simulator on land before departure. Furthermore, the use of a robust reactor design with passive safety systems and minimal risk of meltdown, and radiation monitoring systems onboard and in surrounding environments, were both considered vital by 49% of respondents.

Table 3: The most important safeguards and operational conditions deemed necessary for employment on board a nuclear-powered vessel (% of total respondents, N=497)

Alternative safeguards and operational conditions	%
Comprehensive training for all crew members in nuclear safety and emergency response	78,5
Taking part in training with an advanced simulator on land before departure	52,1
The use of a robust reactor design with passive safety systems and minimal risk of meltdown	48,9
Radiation monitoring systems onboard and in surrounding environments	48,9
Information through workshops and seminars to ensure I understand the risks and benefits	42,5
A radiation-proof reactor enclosure	40,2
Regular inspections and audits by independent nuclear safety authorities	39,4
Information through direct dialogue with the nuclear facility team	31,2
The presence of personnel from the nuclear facility team aboard the vessel	25,4
Adequate insurance for crew and vessel in case of nuclear-related incidents	23,7
Access to a digital team of qualified specialists	12,7
Support systems for crew mental health and well-being	11,7
A pirate-proof reactor enclosure	9,5
I will not consider working on a nuclear-powered ship	5,2

4 DISCUSSION

This study has identified stakeholder groups that, to varying degrees, are essential for the development of nuclear-powered merchant shipping. Using a PESTLE analysis, the external environment has been assessed to identify the key opportunities and challenges associated with introducing nuclear-powered merchant vessels across the political, economic, social, technological, legal and environmental dimensions. Linking these factors to the relevant stakeholder groups establishes a solid basis for coherent implementation strategy and enables the development of targeted, effective risk-mitigation measures. As demonstrated in this study, numerous actors are actively working towards the realisation of nuclear-powered merchant shipping, which is currently regarded as the only viable zero-emission solution for large ocean-going vessels [6].

No nuclear-powered merchant ships currently operate outside of Russia today. Nevertheless, earlier nuclear cargo vessels from the United States, Germany, and Japan offer valuable insights into nuclear ship design, operational practices, and policy frameworks that can inform future regulatory development [34]. Although considerable progress remains to be made, developments are advancing rapidly. As noted by Valiaveedu et al. [34], nuclear propulsion raises ethical concerns

related to safeguards and the potential for piracy. However, these risks can be significantly mitigated through robust legislation, rigorous safety standards, and resilient ship designs, which is also consistent with previous reports [30-34].

This study focuses specifically on the social dimension of the PESTLE analysis, with particular emphasis on the attitudes of crew members in the shipping industry towards employment on board a nuclear-powered vessel. The findings indicate that attitudes towards working on board such vessels are more positive than might be expected, given the current lack of publicly available information and the absence of dedicated training or familiarisation programmes.

Seafaring is widely recognised as a high-risk occupation. Research consistently demonstrates that seafarers face substantially higher mortality, injury, and illness rates than shore-based workers [35-37]. Despite this, prior research demonstrated that subjective risk perceptions among Norwegian fishermen and employees on offshore service vessels were relatively low, and respondents reported limited concerns about risk [38]. Furthermore, these workers perceived it as unlikely that they themselves would be involved in an accident, indicating a clear discrepancy between formally estimated risks and subjective risk perceptions. Similarly, a study within the Norwegian shipping industry reported that the overall safety level was regarded as relatively high by employees, and the perception of risk correspondingly low [39]. Such findings emphasise that subjective perceptions of risk form the basis for risk acceptance, regardless of objective or quantitatively assessed levels of risk [40]. In high-risk occupational environments, downplaying or neglecting danger may function as a coping mechanism that enables individuals to continue performing demanding tasks [38].

These findings may help explain why more than 65% of respondents in the present study expressed a willingness to work on board a nuclear-powered vessel, despite the fact that such ships have not yet been deployed commercially. Limited access to information or insufficient knowledge about the operation of nuclear-powered vessels, may also have contributed to the 27% of respondents who reported being uncertain.

Employees aged 30-39 years reported significantly less positive attitudes towards such employment compared to other age groups. Aside from this, no consistent age-related trend was observed. This aligns with earlier research in the Norwegian shipping industry finding no significant age-based differences in risk perceptions [39], and studies indicating that age is a weak predictor of support for nuclear power [23, 24].

Female employees exhibited significantly less positive attitudes towards working on board a nuclear-powered vessel than male respondents. This finding is consistent with studies indicating that women tend to report higher levels of risk perception than men [20-22, 41]. However, the number of female respondents in the present sample was low, and further research is needed to determine whether this pattern holds in the context of nuclear-powered shipping. Parenthood did not affect the acceptance of nuclear propulsion, consistent with previous research suggesting that risky labour-market behaviour remained unaffected by parenthood [42].

Chief engineers expressed significantly more positive attitudes towards working on board nuclear-powered vessels compared with other occupational groups. Prior studies have shown that individuals with strong backgrounds in science and technology tend to be less risk-averse [25, 26]. Thus, experienced chief engineers with extensive technological competence and familiarity with complex engineering systems may adopt a more science-based assessment of nuclear energy, contributing to more positive attitudes.

Respondents in the present study were predominantly Norwegian or Filipino. The findings indicated that Norwegian respondents expressed significantly more positive attitudes towards working on a nuclear-powered vessel than their Filipino counterparts. Previous research suggests that cultural background can influence how individuals interpret and respond to uncertainty [43, 44], which may partly explain the nationality-based differences observed.

Survey data on attitudes towards nuclear energy provide additional context. A prior study reported that 46% of Norwegian respondents supported the use of nuclear energy in their own country, compared with 52% of Filipino respondents [24]. However, when asked about health and

safety implications, 57% of Norwegians stated that they were very or fairly concerned, whereas the corresponding figure among Filipino respondents was markedly higher at 93% [24]. These substantial differences in expressed concern may help account for the more cautious attitudes observed among Filipino seafarers in the present study. Additional research is, however, needed to clarify which socioeconomic factors exert the strongest influence on attitudes towards employment on board a nuclear-powered merchant vessel.

Operational safeguards on a nuclear-powered vessel extend well beyond reactor design and may include strict nuclear-specific operating procedures, continuous radiation monitoring, advanced crew training, coordinated emergency-preparedness measures involving crew, ports and coastal states, enhanced security protocols, restricted reactor access, secure communication links with national maritime authorities, and cross-border regulatory coordination among others [29-34; 45].

In this study, the highest-priority safeguards identified by respondents as necessary for employment on board a nuclear-powered vessel, were comprehensive training in nuclear safety and emergency response for all crew members, followed by pre-departure training using advanced land-based simulators. This finding is consistent with research demonstrating that crew confidence is directly influenced by the quality, clarity and relevance of their training [46].

Ensuring that crew members feel safe is essential, and cultivating a strong safety culture reinforces trust. Approximately half of respondents also emphasised the importance of radiation monitoring systems on board and in the surrounding environment. Transparent communication regarding radiation levels and safety margins, along with a clearly articulated safety culture, may therefore contribute to strengthening crew confidence [47-48].

Overall, these safeguards are essential not only for ensuring safe nuclear operations at sea, but also for securing stakeholder acceptance, particularly among crew members, whose engagement is central to the successful implementation of nuclear propulsion.

5 CONCLUSION

This study suggests that the successful introduction of nuclear-powered merchant shipping will depend not only on overcoming technological, regulatory, and environmental barriers, but also on securing acceptance among key stakeholder groups – most notably the crew who will operate these vessels. Although seafaring is objectively a high-risk occupation, existing research and the present findings indicate that seafarers' subjective perceptions of risk tend to be comparatively low, which may help explain the relatively high willingness among respondents to consider employment on a nuclear-powered vessel.

These findings suggest that crew members are likely to become supportive stakeholders – provided that their concerns are addressed through rigorous safety measures, effective communication, and meaningful involvement in the implementation process.

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