QUIET AND GREEN: EXPLORING OPPORTUNITIES TO ENHANCE ENERGY EFFICIENCY WHILE SIMULTANEOUSLY ADDRESSING UNDERWATER NOISE IN COMMERCIAL SHIPPING

Dr Seyedvahid Vakili  
University of Southampton

Prof. Paul White  
University of Southampton

Prof. Stephen Turnock  
University of Southampton

ABSTRACT

Underwater Radiated Noise (URN) emerging from international shipping poses a significant challenge to sustainable shipping. This paper explores the nexus between energy efficiency measures and URN reduction, aligning with the International Maritime Organization’s (IMO’s) net-zero emission goals. Investigating the synergy between energy efficiency strategies and URN mitigation, the study addresses the complexities of decarbonizing the maritime sector within a landscape of diverse green technologies. In response to the IMO’s revised Greenhouse Gas strategy (zero emissions by 2050), the study emphasizes the need for modernizing aging vessel fleets and adopting carbon-neutral fuels. Various measures, such as speed reduction, wind-assisted propulsion systems, Energy Saving Devices, and air lubrication systems, show promise in achieving substantial emissions reductions. Notably, the study highlights the substantial URN reduction potential associated with energy efficiency measures. Reductions of 6 dB in URN can be achieved by a 20% vessel speed reduction, while wind-assisted propulsion and air lubrication systems show even greater efficacy, surpassing 10 dB in URN reduction. Considering the aging vessel fleet and upcoming Carbon Intensity Indicator requirements, the adoption of energy-efficiency measures is expected to grow, leading to individual vessel URN reduction. The study correlates influential factors contributing to deep ocean URN, suggesting that energy efficiency measures not only diminish individual ship URN but also mitigate ambient noise equivalently. Anticipating energy efficiency measures contributing up to 32% to GHG reduction by 2050, a 20% speed reduction could yield a 6 dB average global URN reduction, aligning with the Okeanos target of 3 dB per decade. Despite a worst-case scenario projecting a 2.5 dB increases in ambient noise levels by 2050, the study posits that the 32% contribution from energy efficiency measures could counteract the impact of seaborne trade growth, effectively mitigating ambient noise even in challenging scenarios.

1 INTRODUCTION

Shipping, acknowledged as the most effective means of transporting goods, holds a crucial position in worldwide commerce, accounting for approximately 80% of cargo volume. Nonetheless, it presents notable environmental and socio-economic challenges, contributing to 2.89% of global greenhouse gas (GHG) emissions [1]. Among these challenges, Underwater Radiated Noise (URN) arises as a significant issue associated with commercial ships. URN, although not visually perceptible like other pollutants, imposes harmful effects on marine ecosystems.

The continual growth of maritime trade, alongside the expansion of the global fleet in terms of both quantity and size, as well as the increased distances covered, likely contributes to heightened URN emissions from commercial vessels. Many studies have highlighted the environmental ramifications of this phenomenon, as well as its adverse impacts on marine life, such as fish, invertebrates, and marine mammals, leading to ecological shifts and changes in population dynamics [2,3].

While commercial shipping is acknowledged as a significant contributor to URN, the precise relationship between URN emissions from commercial vessels, maritime traffic, and comprehending the adverse impacts of URN on marine ecosystems is still in its early stages and requires further investigation. Given the complexity of this issue, a comprehensive, systematic, and transdisciplinary approach involving various stakeholders, including but not limited to ship designers, builders, operators, seafarers, ports, policymakers, technology providers, and classification societies, is necessary [4]. Due to the transboundary nature of URN pollution, international, regional, and national
cooperation is imperative for its management [4]. To tackle this challenge, prominent international agencies like the International Maritime Organization (IMO) and the European Union (EU), alongside other regional and national agreements, play pivotal roles in monitoring, regulating, and mitigating URN emissions from commercial vessels.

The IMO has introduced voluntary guidelines and resolutions aimed at mitigating URN emissions from commercial shipping. The 2014 IMO guidelines focused on strategies such as routing adjustments, operational changes, and improvements in ship design and maintenance to address URN [5]. During MEPC 80, revised non-binding IMO guidelines for URN reduction were endorsed, and applicable to both new and existing vessels. These updated guidelines recognize the interconnectedness of maritime issues, emphasizing the need to address URN alongside concerns like zero emissions, biofouling, and vessel safety. Additionally, the Sub-Committee on Ship Design and Construction has developed an Action Plan to further prevent and diminish URN emissions from ships, aiming to mitigate their detrimental impacts on marine ecosystems, particularly marine wildlife and indigenous communities [6].

Meanwhile, the European Union has addressed the issue within the Marine Strategy Framework Directive. Member states have tasked the EU with evaluating and documenting anthropogenic noise as part of Descriptor 11 of the MS FD, adopted in June 2008. The primary goal of this Directive is to achieve a state of good environmental health by 2020, with each member state devising its own strategy to reach this objective [5].

While URN emerges as a growing environmental concern, many technical and operational strategies are available to minimize URN emissions from commercial vessels. However, to engage stakeholders in actively reducing URN emissions from these vessels and hastening the overall reduction process, it's crucial to align these efforts with the reduction of GHG emissions from shipping, which is the primary concern of the industry [7]. Considering this, the paper aims to identify the synergy between reducing GHG emissions and URN from commercial vessels. The study's novelty lies in identifying measures that can enhance energy efficiency, thereby reducing GHG emissions and URN simultaneously, while considering their potential in each criterion. The study's findings can serve as a guideline for shipowners and policymakers to adopt the most cost-effective measures to meet both the IMO's revised GHG strategy and reduce URN emissions from commercial vessels.

2 ZERO EMISSION SHIPPING

The IMO, as the regulatory authority for international shipping, has revised its strategy to achieve zero-emission shipping by approximately 2050 [8]. However, achieving this goal necessitates a combination of measures rather than a single solution. To attain zero-emission shipping by the mid-21st century, the maritime sector can leverage a range of operational and technical strategies. These measures span across hull design [11], economic scale, power and propulsion systems, speed optimization, fuel selection, and weather and voyage planning [7, 9]. It is suggested that a synergistic implementation of these measures could potentially achieve a 75% reduction in GHG emissions [12] (Figure 1).

Among these measures, the use of carbon-neutral fuels stands out as a key strategy for mitigating GHG emissions from shipping. Nevertheless, various significant barriers exist, such as challenges related to the availability and cost of alternative fuels, inadequate infrastructure, logistical constraints, limited scalability of production, technological maturity in onboard vessel systems and supply-side infrastructure, considerations regarding ship and engine design, crew training, safety considerations, and substantial financial investments [7]. As a result, the widespread adoption of carbon-neutral fuels is expected to gain traction after 2030 and become predominant beyond 2040 [9]. In response to these barriers, the maritime industry is compelled to implement a range of measures. These include the adoption of energy-efficient technologies, such as speed reduction, and the optimization of logistics to align with the emissions reduction objectives set by the IMO. The implementation of energy efficiency improvement measures, including speed reduction, plays a crucial role in mitigating GHG emissions from the shipping sector. By 2050, these measures have the potential to contribute to a significant 32% reduction in GHG emissions from the industry. This reduction comprises an estimated
23% reduction through speed reduction and around 9% through improvements in energy efficiency [10].

![Image of shipping decarbonization technologies' GHG emissions reduction potential.]

Figure 1. Shipping decarbonization technologies' GHG emissions reduction potential.

3 URN TREND AND ACTIONS

Anthropogenic noise levels exhibit variation both spatially and temporally, influenced not only by the intensity of human activity but the acoustic properties of the area. Understanding the diverse sources of underwater noise and their cumulative effects on the acoustic environment is important. Industrial and shipping development stands as a significant contributor to the notable rise in underwater noise, alongside activities like seismic surveys, explosions, and wind-related factors. While shipping elevates underwater ambient noise, the precise impact of commercial shipping remains unclear and requires further investigation.

Research indicates a gradual increase in ambient noise levels, approximately 3 dB per decade in certain regions [13, 14, 15]. However, it's noteworthy that this trend isn't consistent globally; some areas have shown stability or even a decrease in noise levels. Moreover, there are disparities in the projected underwater noise levels across different regions worldwide [16]. These variations highlight the necessity to move beyond linear models and consider nonlinear trends that encompass long-term cyclic dynamics. Achieving this necessitates at least three decades of uninterrupted monitoring to identify trends comparable to the historical noise level increases observed in the Northeast Pacific [17].

The COVID-19 pandemic provided valuable insights into the potential impact of reduced human activities on ocean ambient noise levels. The decrease in shipping activity led to a 6% reduction in global shipping noise source energy within the 63 Hz 1/3 octave band, returning noise levels to those last observed in 2017 [14]. Notably, these reductions were unevenly distributed, with significant local decreases occurring in areas where transportation links, such as ferries, ceased operations during the pandemic, as well as along major shipping routes between China and the EU.

Considering the significant impact of shipping growth on the trend of URN, it is imperative to account for the expansion of shipping activities. The IMO's Fourth GHG Study offers a comprehensive forecast of transport activity up to 2050, delineated across four distinct scenarios. When evaluating the density of shipping traffic, understanding not only the volume of trade but also the distances travelled...
becomes crucial, making transport work (i.e., cargo carried multiplied by distance travelled) a more insightful metric than cargo volume or value. The projections outlined in the Fourth GHG study anticipate a growth in transport work ranging from 40% to 100% from 2020 to 2050 [1], translating to an average annual growth rate of approximately 1.21% to 2.33%.

In a worst-case scenario of a 2.33% yearly growth rate, looking forward to the next decade, by 2033, the authors anticipate a roughly 26% increase in transport work, accompanied by a corresponding rise in average shipping density. According to Equation 1 from Ross's 1976 study [17], the formula $L_n = L_s - 95 + 10 \log \delta + 10 \log \frac{1}{\alpha}$ specifies the ambient noise level in dB, where $L_n$ is the ambient noise, $L_s$ is the average sound source level per ship, $\delta$ represents the density of ship traffic, $\alpha$ is the attenuation factor, and $H$ denotes the water depth.

Assuming the only variable change is an increase in traffic density, it would lead to an approximate increase of 1 dB in ambient URN. To counteract this rise and achieve the proposed 3 dB reduction advocated by Okeanos, an average reduction of 4 dB in the source level per ship would be necessary. Looking ahead to 2050 and employing the same growth rate, an 78% surge in transport work is projected. Utilizing the Ross equation and assuming no other alterations, this would correspond to an approximate 2.5 dB increase in ambient URN. To offset this rise and fulfill the 3 dB per decade reduction target proposed by Okeanos, a reduction of 10.6 dB in the average source level per ship would be required.

4 SYNERGY BETWEEN IMPROVEMENT OF ENERGY EFFICIENCY AND REDUCTION OF URN FROM COMMERCIAL VESSEL

URN has emerged as a growing environmental concern, with significant repercussions for marine species. Many technical and operational strategies are available to minimize URN emissions from commercial vessels. However, to engage stakeholders in actively reducing URN emissions from these vessels and accelerating the overall reduction process, it's important to align these efforts with improvements in vessel energy efficiency [18].

Improving energy efficiency while reducing URN presents a few certain contradictions, including: i) increasing blade area at the propeller to mitigate cavitation, resulting decrease in propeller efficiency [20]; ii) speed reduction may not necessarily lead to a reduction in URN for Controllable Pitch Propeller (CPP); and iii) implementing technologies like scrubbers and onboard carbon capture may lead to increase in machinery noise. However, many energy efficiency measures exist that can simultaneously enhance energy efficiency and mitigate URN emissions [7].

It is significant to note that cavitation emerges as a primary source of noise once the vessel reaches its Cavitation Inception Speed (CIS) [20]. Consequently, optimizing the propeller in conjunction with the ship's hull configuration plays a significant role in reducing cavitation and, consequently, mitigating URN emissions from commercial vessels. Additionally, the implementation of Energy Saving Devices (ESDs) and Propulsion Improvement Devices (PIDs) has the potential to enhance both energy efficiency (by up to 10%) and URN reduction (by up to 5 dB), often resulting in short payback periods as an added benefit [21].

Innovative energy efficiency measures, such as air lubrication systems and wind-assisted propulsion systems, present promising solutions with positive impacts on URN reduction (exceeding 10 dB and up to 10 dB, respectively) and the enhancement of energy efficiency (15% and up to 25%, respectively) [7]. However, there exists a gap in research examining the real-world effectiveness of these methods in mitigating URN emissions from commercial vessels, highlighting the necessity for full-scale evaluations to assess their effectiveness and reliability.

Furthermore, as the maritime industry transitions towards vessel electrification, the adoption of fuel cell, battery, or hybrid technologies, particularly in short sea shipping, offers significant potential for
improving energy efficiency (up to 10%). Within these electrified systems, incorporating azimuth propulsion and podded propulsors, along with their associated machinery, can substantially reduce URN emissions from vessels (by over 10 dB) [7, 21].

Machinery noise is the dominant contributor to URN emissions in commercial vessels during operations below the CIS. Achieving reductions in URN from machinery in commercial vessels can be based on various strategies, including enhancing machinery design, utilizing quieter machinery, optimizing the layout of engine rooms and machinery placement, and implementing resilient mounting systems [15, 21]. It is crucial to stress that, in addition to assessing the noise generated by individual machinery components, a comprehensive evaluation must consider the interaction and combined contribution of all the machinery as an integrated system [4].

Like efforts aimed at decreasing GHG emissions in the shipping sector, operational strategies are pivotal in mitigating URN emissions from commercial vessels. Understanding the relationship between power and the cube of speed offers a significant opportunity for improving energy efficiency through speed reduction [7]. Furthermore, the direct correlation between vessel speed and cavitation underscores the importance of speed reduction, particularly for vessels with fixed pitch propellers. Such reductions can lead to a substantial decrease in URN emissions, with a 10% reduction in speed resulting in around 2 dB reduction in mean source level and a 20% reduction in speed leading to a predicted mean source level decrease of 6 dB across all frequencies for fixed pitch propellers [23] (Figure 2).

However, it's worth noting that speed reduction may increase URN emissions from CPP. Nonetheless, optimizing CPP combinator settings can be crucial in mitigating early cavitation onset on both the pressure and suction sides during constant-speed operations and acceleration. These optimization measures can simultaneously enhance propeller efficiency under such operating conditions. Moreover, other operational and technical measures are available to reduce URN emissions from CPP-equipped vessels. Additional operational measures include vessel hull and propeller cleaning and maintenance, passage planning, and the use of weather routing strategies. These measures have the potential to improve both energy efficiency (up to 5%) and URN reduction (up to 5 dB) in commercial vessels without imposing significant additional costs on shipowners, thus creating a mutually beneficial arrangement for all stakeholders involved [7]. However, ensuring the safety of these vessels and their operations remains paramount due to their sensitivity and the importance of high maneuverability.
5 DISCUSSION AND CONCLUSIONS

This study aims to evaluate the relationship between initiatives aimed at improving ship energy efficiency and mitigating URN emissions. As the maritime industry strives to adhere to the IMO revised GHG strategy, efforts are underway to identify effective strategies for reducing GHG emissions and transitioning towards a zero-emission sector. This involves modernizing and rejuvenating aging vessel fleets, as well as adopting carbon-neutral fuels, all amidst a landscape of evolving green technologies.

Adding to the complexity of this endeavour is the prolonged lifespan of ships, where some vessels are too old for retrofitting yet too young for scrapping. Recognizing the absence of a singular solution for decarbonizing the maritime sector, a diverse range of measures shows significant potential for achieving substantial emissions reductions. These measures include adopting carbon-neutral fuels and improving energy efficiency through measures like speed reduction and logistics optimization. While carbon-neutral fuels are pivotal in decarbonizing the shipping industry, barriers associated with their utilization have led the industry to pursue alternative measures. Considering the aging vessel fleet, forthcoming stringent requirements like the Carbon Intensity Indicator, and the anticipated high costs of alternative fuels, the study anticipates a rising trend of vessels implementing energy efficiency measures to align with the IMO’s revised GHG strategy targets.

With the reduction of GHG emissions becoming a primary concern for the shipping industry and URN emerging as a negative impact of shipping, there exists a synergy between these externalities. Shipowners and the environment stand to benefit concurrently by reducing URN emissions and improving energy efficiency. Studies indicate that the majority of energy efficiency measures have the potential to decrease URN emissions from ships, thereby presenting a win-win situation for shipowners. However, for safe and cost-effective operation, shipowners must maintain discretion in selecting appropriate measures.

The study anticipates that strategies such as speed reduction, wind-assisted propulsion systems, ESDs, and air lubrication systems will play crucial roles in realizing the IMO GHG reduction strategy. Furthermore, as the maritime sector transitions towards vessel electrification, the adoption of fuel cells, batteries, or hybrid technologies, especially in short sea shipping, holds significant promise for improving energy efficiency and accelerating progress in alignment with the IMO’s GHG reduction strategy.

The study emphasizes the significant correlation between the adoption of energy efficiency strategies and the reduction of URN. Findings indicate that a 20% reduction in vessel speed can yield a notable 6 dB decrease in URN for fixed-pitch propeller vessels. Wind-assisted propulsion systems show potential for URN reduction of up to 10 dB, while air lubrication systems offer even greater reductions, exceeding 10 dB in URN reduction.

Moreover, additional operational measures such as vessel hull and propeller cleaning and maintenance, optimizing vessel handling, meticulous passage planning, and utilizing weather routing strategies, provide opportunities to improve both energy efficiency and URN reduction in commercial vessels. Importantly, these measures do not entail significant additional costs for shipowners, establishing a mutually beneficial arrangement for all stakeholders involved.

Although there is a projected increase in ambient noise of approximately 3 dB per decade in certain regions globally, this trend is not consistent across all areas, with some regions experiencing a plateau or even a decrease in noise levels. Furthermore, discrepancies in the forecasts of underwater noise levels in different regions necessitate nonlinear models that can accommodate long-term cyclic dynamics. Projections indicate that transport activity could see a surge to an annual growth rate of approximately 1.21% to 2.33%. By 2033, to achieve the targeted 3 dB reduction proposed by Okeanos, an average reduction of 4 dB per ship in source level would be necessary and this would be 10.6 dB per ship in source level for 2050. Despite a worst-case scenario in ambient noise levels
by 2050, the study posits that the 32% contribution from energy efficiency measures could counteract the impact of seaborne trade growth, effectively mitigating ambient noise even in challenging scenarios.

It is important to underscore the importance of focusing on the deep sea for more precise predictions of URN on a global scale. The variation in low-frequency ocean sound increase across different regions cautions against generalizing about uniformly escalating low-frequency sound levels worldwide. Additionally, the coastal enhancement effect\[^{1}\] needs consideration when examining factors influencing ambient noise, as it amplifies URN from coastal sources, making them audible in the deep ocean.

In summary, enhancing energy efficiency is pivotal in aligning with the revised GHG strategy outlined by the IMO. The implementation of energy efficiency measures is anticipated to result in quieter vessels compared to conventional ones, thus supporting the reduction of URN from commercial vessels. Vessel owners have the opportunity to improve efficiency in accordance with the IMO's GHG strategy, enabling the pursuit of zero-emission shipping goals while concurrently mitigating URN, without incurring additional costs. This scenario presents a mutually beneficial arrangement. However, it prompts the question of whether distinct regulatory frameworks and specific noise reduction targets remain necessary given the potential noise reduction achieved through GHG strategy adherence.

The effectiveness of GHG emission regulations in reducing URN from commercial vessels greatly hinges on the approach taken to achieve zero-emission shipping by 2050. While the use of carbon-neutral fuels may not significantly impact URN reduction, the greater role played by energy efficiency measures in the industry's decarbonization endeavours increases the likelihood of URN reduction from commercial vessels. Addressing this inquiry requires a comprehensive investigation to elucidate the intricate relationship between energy efficiency measures and compliance with the IMO's GHG strategy, particularly regarding their influence on underwater noise reduction within the domain of commercial vessels.

6 REFERENCES


\[^{1}\] The coastal enhancement effect is “a mechanism whereby sounds from near-surface sources can be propagated to a distant receiver by low-loss, deep channel, near-horizontal refractive paths.”