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REVIEW OF COST-EFFECTIVE GREEN SHIP TECHNOLOGIES FOR DEVELOPING NATIONS: A CASE STUDY OF THE NIGERIAN SHIPBUILDING INDUSTRY

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Abstract

The maritime industry in Nigeria is critical to the nation's economy but remains a significant contributor to greenhouse gas (GHG) emissions due to aging fleets, reliance on heavy fuel oil (HFO), and limited adoption of green technologies. This review evaluates cost-effective green ship technologies identified in the literature—hull optimization, renewable energy integration, alternative fuels, and waste heat recovery systems—assessing their potential applicability and economic viability considering the challenges and opportunities in Nigeria. Synthesizing findings from stakeholder reports, comparative analyses of international case studies, and technical literature, this review suggests these technologies could potentially reduce fuel consumption by up to 30% and cut emissions by 5–30%, offering cost savings for shipowners. A synthesis of cost-benefit data indicates potential payback periods ranging from 1 to 8 years, varying significantly by technology and implementation context, highlighting economic feasibility under certain conditions but also significant investment needs. The paper concludes by summarizing the reviewed solutions and offering actionable policy recommendations derived from best practices to enhance capacity building, incentivize investments, and modernize Nigeria's maritime infrastructure, paving the way for a more sustainable and competitive industry.

Keywords: green shipping technologies, hull optimization, alternative fuels, renewable energy, cost-benefit analysis, maritime sustainability, Nigeria, literature review.

1.0 INTRODUCTION

The maritime sector is indispensable to Nigeria's economy, handling over 95% of its trade volume and contributing significantly to national GDP, with potential to reach 10% (Nigerian Maritime Administration and Safety Agency, 2019; Nigerian Shippers' Council, 2024).[1] Nigeria also accounts for a substantial share (65-70%) of West African cargo throughput (NIMASA, 2019).[1] However, this vital sector is a major source of greenhouse gas (GHG) emissions, largely due to its reliance on aging fleets and high-sulfur marine fuels (International Maritime Organization [IMO], 2020). Globally, shipping contributes around 3% of GHG emissions, a figure that increased by 20% between 2012 and 2018 (United Nations Conference on Trade and Development, 2023; IMO, 2021 cited in). With international efforts intensifying under the revised 2023 IMO GHG Strategy aiming for net-zero emissions by or around 2050 (IMO, 2023) , Nigeria's maritime industry faces immense pressure to adopt greener practices (UNCTAD, 2024). Recent statements from Nigeria's Minister of Marine and Blue Economy and the NIMASA Director General emphasize the nation's intent to leverage renewable energy and pursue green shipping initiatives (NIMASA, 2025).

Despite this ambition and the global push, Nigeria's maritime sector confronts unique and significant challenges that hinder the transition to sustainable shipping.

- **Aging Fleet:** A primary issue is the age of Nigeria's merchant fleet. Over 60% of vessels operating in its waters exceed 20 years of service (NIMASA, 2022). This is part of a global trend, with the average world ship age being 22.2 years in early 2023 (UNCTAD, 2023).Older vessels typically feature inefficient propulsion systems, outdated hull designs, and incur higher maintenance costs, leading to significantly higher carbon emissions (Clarksons Research, 2021). Studies suggest these older vessels consume 20–30% more fuel than modern counterparts (IMO, 2020). Replacing these vessels is often prohibitively expensive for operators, especially small and medium-sized enterprises (SMEs). Retrofitting existing vessels with green technologies like optimized hull designs or waste heat recovery systems presents a more feasible option (Alderton & Winchester, 2022; Stopford, 2021). However, a critical barrier is the limited technical capacity and skills gap within Nigerian shipyards to perform these complex retrofits and maintain new technologies (Folarin, 2020; Ebong, 2023; Okorie, 2020). A 2008 NIMASA/NCDMB survey already highlighted low capacity among

seafarers (Okorie, 2020) , and this skills deficit persists. Targeted investments in shipyard modernization and comprehensive workforce training, potentially enhancing existing programs like NIMASA's Nigerian Seafarers Development Programme (NSDP) (NIMASA, 2021) , are essential. Financial incentives, such as subsidies or tax breaks, are also needed to encourage retrofitting adoption (UNCTAD, 2021).

- **Fuel Dependence:** The sector heavily relies on high-sulfur heavy fuel oil (HFO), which accounts for over 90% of marine fuel consumed in Nigerian waters (IMO, 2020). HFO is environmentally damaging and increasingly expensive. Transitioning to cleaner alternatives like Liquefied Natural Gas (LNG) and biofuels is crucial. LNG offers environmental benefits, reducing CO_2 emissions by 20–30% compared to HFO (Clarksons Research, 2021; Perčić et al., 2023). Nigeria's vast natural gas reserves present a strategic advantage. However, a major bottleneck is the *critical lack* of LNG bunkering infrastructure in major ports like Lagos and Port Harcourt (Ebong, 2023; DNV, 2025). Globally, LNG bunkering ports are expanding (191 active, 81 under construction in 2024) , but Nigeria lags significantly. Furthermore, large investments in LNG infrastructure face risks, including potential stranded assets due to the global push towards net-zero by 2050 potentially bypassing transition fuels like LNG, market price volatility, competition from established suppliers, and potential conflict with economic diversification goals (IISD, 2024). Biofuels, potentially derived from local feedstocks like cassava and palm oil residues (Salami & Okejiri, 2020; Simonyan & Fasina, 2013), offer another path. Studies suggest potential emission reductions of around 30% (UNEP, 2021). However, significant challenges exist: competition with livestock feed and soil health needs (Ogunjobi et al., 2020) , serious food security concerns if edible crops (like palm oil) or staple foods (like cassava) are diverted , inconsistent policy implementation (Ogunjobi et al., 2020) , potentially high production costs (Simonyan & Fasina, 2013) , and sustainability issues related to land use change (Carvalho et al., 2021). Biogas from waste might offer a more sustainable route (Simonyan & Fasina, 2013).
- **Infrastructure Deficiencies:** Nigeria's port infrastructure is generally insufficient to support green shipping practices (Nigerian Ports Authority [NPA], 2022). Facilities like shore power systems, which allow docked vessels to use grid electricity instead of auxiliary engines, are largely absent. Implementing shore power requires substantial investment in grid upgrades and port modernization (UNCTAD, 2021). The lack of LNG bunkering facilities is another

prime example of this deficit. Furthermore, limited technical expertise in shipyards constrains the implementation and maintenance of green technologies (Folarin, 2020; Ebong, 2023; Okorie, 2020). Systemic issues like inadequate enforcement capacity and potential corruption can also hinder infrastructure development and technology adoption (Ebong, 2023; Okorie, 2020). Addressing these infrastructure and institutional gaps is vital for enabling the transition.

This paper reviews potential cost-effective green ship technologies identified in the literature, considering their applicability within Nigeria's challenging context. By synthesizing information on hull optimization, renewable energy, alternative fuels, and waste heat recovery, this review aims to provide insights for transitioning Nigeria's maritime industry towards sustainability while supporting its economic development.

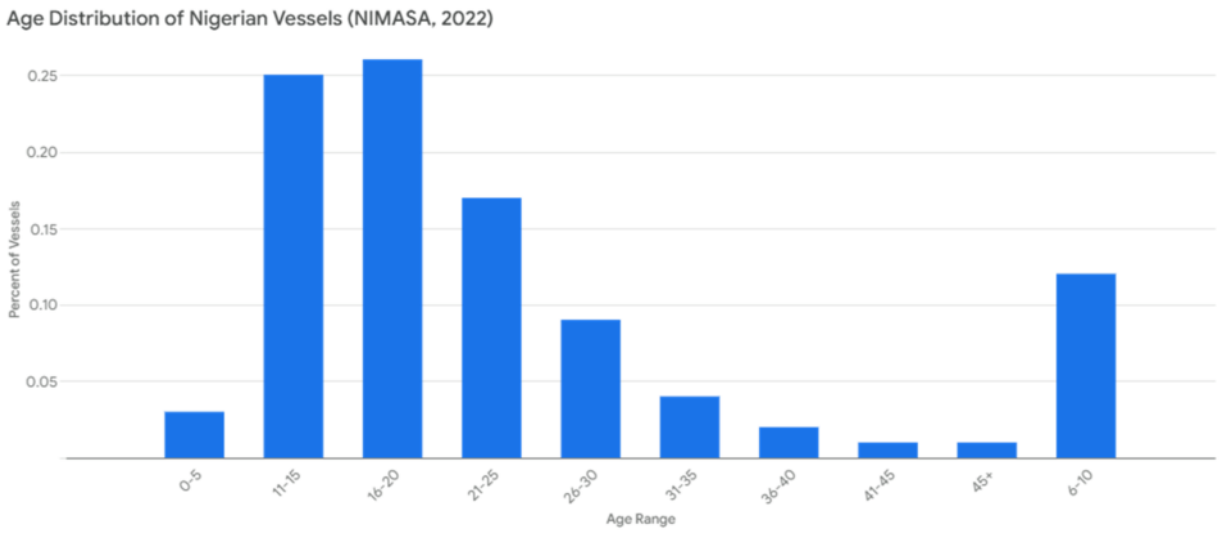


Figure 1: Bar chart showing the age distribution of Nigerian vessels (Source: NIMASA, 2022).

2.0 METHODOLOGY OF THE REVIEW

This study employs a qualitative review methodology to synthesize existing knowledge on cost-effective green ship technologies and assess their potential application within the Nigerian maritime context. The approach integrates insights from stakeholder perspectives reported in official documents, comparative analysis of international case studies, and a review of technical and economic literature on green shipping solutions. The goal is to provide a structured overview of potential pathways for Nigeria, grounded in existing evidence, rather than generating new primary data or simulation results.

- **Literature Synthesis:** A targeted literature search was conducted using academic databases (like Web of Science, Scopus, Google Scholar) and institutional repositories (IMO, UNCTAD, NIMASA, World Bank, IEA, IRENA). Keywords included combinations of "green shipping," "maritime decarbonization," "Nigeria," "developing nations," "hull optimization," "alternative fuels," "LNG," "biofuels," "renewable energy," "solar shipping," "wind-assist," "waste heat recovery," "cost-benefit analysis," "ship retrofitting," "maritime policy," "skills gap," and "infrastructure." The selection focused on peer-reviewed articles, reputable industry reports, policy documents, and case studies published primarily between 2018 and 2025 to ensure relevance, although foundational earlier works were also considered. This process draws inspiration from systematic review principles and bibliometric analysis methodologies used in green shipping research (Chen et al., 2024; Psaraftis et al., 2024; Zhao et al., 2025), although a full bibliometric analysis was outside the scope. Thematic synthesis was used to integrate findings across diverse sources.
- **Stakeholder Perspective Integration:** Insights regarding the challenges, priorities, and perspectives of key Nigerian maritime stakeholders (NIMASA, NPA, shipowners, shipyards) were gathered from published reports, official statements, and academic studies analyzing the Nigerian context (NIMASA, 2019; NIMASA, 2022; Ebong, 2023; Okorie, 2020). These perspectives informed the assessment of technology feasibility and the identification of implementation barriers. Input from international organizations (IMO, 2020; UNCTAD, 2023; UNEP, 2021) provided context on global standards and best practices.
- **Comparative Analysis Synthesis:** Case studies and experiences from other developing nations with similar maritime reliance or transition efforts (Indonesia, Brazil, India, South

Africa) were reviewed based on available literature (Carvalho et al., 2021; Dewi et al., 2020; Haryanto et al., 2023; Purnomo et al., 2021; Rahmawati et al., 2021; Setiawan et al., 2020; UNCTAD, 2023). Lessons learned regarding policy effectiveness, infrastructure development strategies (particularly LNG and biofuels), public-private partnerships, and common barriers were synthesized to draw parallels and contrasts relevant to Nigeria. For instance, Indonesia's experience leveraging domestic gas reserves for LNG bunkering, while facing infrastructure hurdles (Purnomo et al., 2021; Rahmawati et al., 2021), and Brazil's integration of biofuels amidst land use and sustainability considerations (Carvalho et al., 2021; Hakirevic Prevljak, 2024), provided valuable comparative insights.

- **Technology Assessment Framework:** The review assessed four key technology categories (hull optimization, renewables, alternative fuels, waste heat recovery) based on criteria derived from the literature: technical feasibility (maturity, applicability to existing fleet), environmental impact (emission reduction potential), economic viability (reported costs, savings, payback periods), and implementation requirements (infrastructure, skills, policy support) specifically considering the Nigerian context. Data on costs and benefits were synthesized from multiple sources to provide indicative ranges, acknowledging inherent uncertainties and variations.

This multi-faceted review methodology allows for a comprehensive assessment of cost-effective green ship technologies, grounding the analysis in documented stakeholder views, international experiences, and technical-economic data relevant to Nigeria's specific circumstances. Figure 2 outlines this review process.

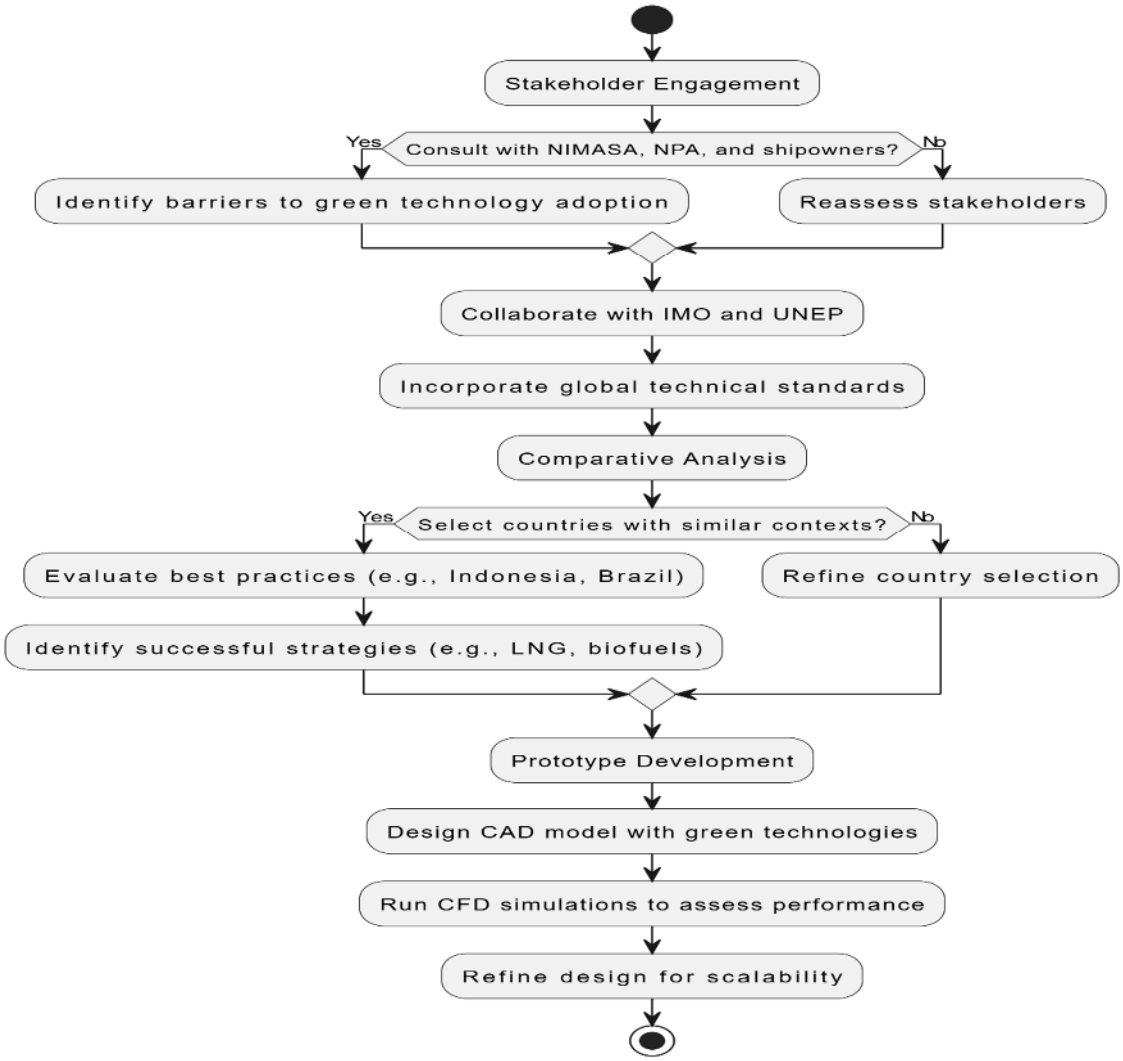


Figure 2: Methodology for Reviewing Green Ship Technologies for Nigeria.

3.0 REVIEW OF POTENTIAL GREEN SHIP TECHNOLOGIES FOR NIGERIA

Based on the literature review and comparative analysis, four key categories of green ship technologies appear particularly relevant for consideration within the Nigerian maritime sector due to their potential cost-effectiveness and environmental benefits. Their feasibility, however, is heavily influenced by the challenges outlined previously.

- **3.1 Hull Optimization:** This is frequently cited as one of the most cost-effective methods for improving fuel efficiency and reducing emissions, especially pertinent for Nigeria's aging fleet (NIMASA, 2022; Alderton & Winchester, 2022). Techniques include applying low-

friction/anti-fouling coatings, installing bulbous bows or stern flaps, using air lubrication systems (ALS), and adding Energy Saving Devices (ESDs) like pre-swirl ducts (e.g., Becker Mewis Duct®) or post-swirl fins (e.g., Propeller Boss Cap Fins - PBCF).[2928]

- *Performance:* Literature suggests potential fuel consumption reductions of 10–15% are achievable through comprehensive hull optimization.[2828] Specific measures report varying savings: coatings 5-10%, ALS 5-10%, Becker Mewis Duct® up to 10%, PBCF 4-5% (ShipUniverse, 2025).[28]
- *Economics:* Costs vary widely. Basic coatings might cost \$50-\$80/m² plus application (ShipUniverse, 2025) [28], potentially aligning with the lower end of the \$15,000–\$25,000 range mentioned in the original paper's Table 1 for simpler retrofits. However, more advanced ESDs can cost \$100,000–\$400,000, and ALS \$500,000–\$1M (ShipUniverse, 2025).[28] Payback periods are reported as 3-12 months for coatings, 1-3 years for ESDs, and 2-4 years for ALS (ShipUniverse, 2025) [28], making simpler options economically attractive.
- *Nigerian Context:* While cost-effective, implementation requires shipyard capacity and technical skills currently limited in Nigeria (Okorie, 2020; Ebong, 2023).[9] Investment in training and shipyard upgrades is necessary to realize this potential.

- **3.2 Renewable Energy Integration:** Integrating solar panels (photovoltaics - PV) for auxiliary power and wind-assist propulsion systems offers sustainable fuel reduction pathways (UNEP, 2021).
  - *Performance:* Solar PV can reduce auxiliary fuel consumption by 5–10% (as simulated in the original paper's methodology section, citing UNEP, 2021). Wind-assist systems (e.g., Flettner rotors, rigid sails) report fuel savings potential of 5–20% (ShipUniverse, 2025).[28]
  - *Economics:* Costs and payback periods are highly debated and context-dependent. The original paper's estimate of \$20,000–\$30,000 for solar with a 2–3 year payback appears highly optimistic. Terrestrial solar PV payback averages 7-10+ years (EnergySage, 2025; GreenLancer, 2024) [30], and maritime applications may face longer periods (e.g., 10-16+ years suggested by Theocharis et al., 2014).[32] Wind-assist installation costs are reported between \$500,000–\$3M with payback periods of 3–7 years (ShipUniverse, 2025) [28], significantly higher than the original paper's estimate. While renewable costs have fallen generally (IRENA, 2023) [33], recent volatility exists [3333], and high perceived risks and financing challenges often hinder adoption in developing countries (Donastorg et al., 2021).[34]
  - *Nigerian Context:* High upfront costs and the need for specialized installation/maintenance expertise are significant barriers.[34] Strong policy support and innovative financing mechanisms would be crucial (Donastorg et al., 2021).[34]
- **3.3 Alternative Fuels:** Transitioning from HFO to cleaner fuels like LNG and biofuels is a major focus globally (IMO, 2023; UNCTAD, 2023).[4]
  - *LNG:* Offers 20–30% CO_2 reduction and eliminates most SOx/PM emissions (Clarksons

Research, 2021; Perčić et al., 2023).[12] Nigeria's gas reserves are an advantage.[1313] However, the *lack of LNG bunkering infrastructure* is a critical barrier in Nigeria.[9] Economic feasibility is highly sensitive to volatile LNG prices and CO_2 taxes, requiring long-term contracts to mitigate risk (Perčić et al., 2023).[12] Significant investment also carries the risk of stranded assets as the world moves towards potentially zero-carbon fuels like green hydrogen or ammonia post-2030.[2013]

- *Biofuels:* Potential feedstocks in Nigeria include cassava residues, palm oil residues, and sweet sorghum (Simonyan & Fasina, 2013; Ogunjobi et al., 2020).[18] Potential for ~30% emission reduction exists (UNEP, 2021). However, major challenges include competition with food/feed, food security risks (especially with cassava/palm oil), land use change impacts, inconsistent policies, and potentially high costs (Simonyan & Fasina, 2013; Ogunjobi et al., 2020; Carvalho et al., 2021).[18] Brazil's experience highlights both opportunities and complexities (Carvalho et al., 2021; Hakirevic Prevljak, 2024).[19] Sustainable sourcing and focusing on non-food/waste feedstocks (like biogas from waste) are critical (Simonyan & Fasina, 2013).[17]
- *Nigerian Context:* Both LNG and biofuels require substantial, coordinated infrastructure development and clear, consistent policy frameworks, currently lacking.[9] The skills gap also affects the ability to operate and maintain vessels using these fuels.[10]

- **3.4 Waste Heat Recovery Systems (WHRS):** These systems capture exhaust heat to generate auxiliary power, improving energy efficiency (IMO, 2020).
  - *Performance:* Reported fuel savings typically range from 5% to 8% (IMO, 2020), potentially higher when bundled with other technologies (IEA, 2023).[35]
  - *Economics:* Generally considered cost-effective, especially for larger vessels with high engine loads. Recent market reports indicate a growing market driven by energy efficiency goals and rising energy costs (Custom Market Insights, 2024; Polaris Market Research, 2024; Market.us, 2025).[36] Costs cited in the original paper ($50,000–$70,000) and payback periods (2–3 years) appear plausible based on general industry data, although specific costs depend heavily on system size and vessel type. High initial investment can still be a barrier (Custom Market Insights, 2024).[38]
  - *Nigerian Context:* Feasible for larger vessels in the Nigerian fleet, but requires specialized technical expertise for installation and maintenance, linking back to the skills gap challenge.[8]

In summary, while these technologies offer potential pathways for greening Nigeria's maritime sector, their successful adoption hinges on addressing the deep-seated challenges related to fleet age, infrastructure deficits, workforce skills, policy implementation, and financing.

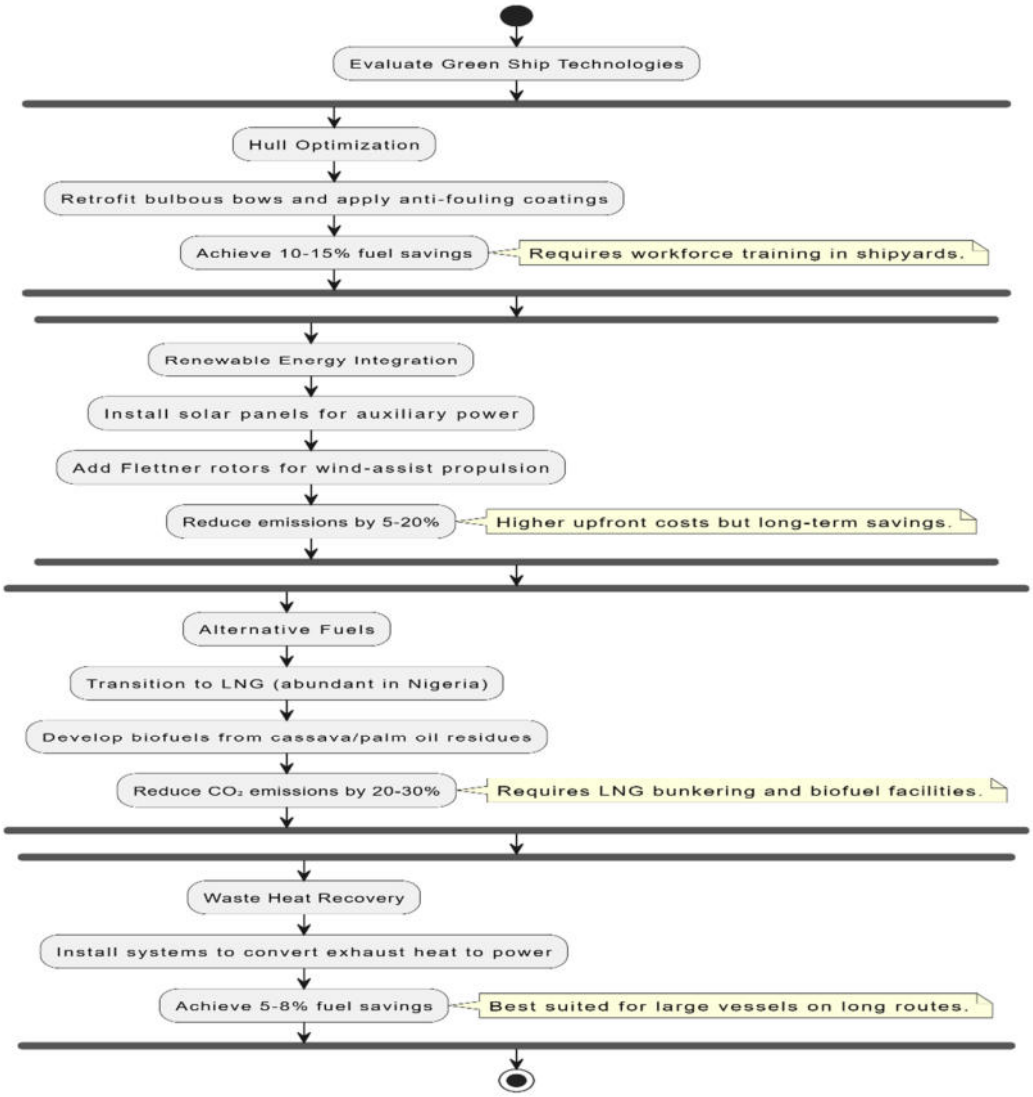


Figure 3: Overview of Reviewed Green Ship Technologies.

4.0 SYNTHESIZED COST-BENEFIT ANALYSIS

Evaluating the economic viability of green ship technologies is crucial for adoption, particularly in developing nations like Nigeria. This section synthesizes cost-benefit data reported in recent literature and market analyses, applying it indicatively to the Nigerian context. It's important to note that actual costs and benefits vary significantly based on vessel type, operational profile, fuel price fluctuations, technology specifics, installation quality, and available policy support. The

figures presented here, especially payback periods, should be viewed as indicative ranges derived from external sources, highlighting potential rather than definitive outcomes. Table 1 provides a summary.

Table 1: Indicative Cost-Benefit Synthesis of Proposed Green Technologies for Nigerian Maritime Sector

Technology	Indicative Initial Cost (USD)	Estimated Annual Savings (USD)	Estimated Payback Period (Years)	CO_2 Reduction Potential (%)	Key Assumptions / Data Source	Major Implementation Barriers (Nigeria Context)
Hull Optimization (Basic)	15,000–50,000^a^	~100,000^b^	1–2	10–15	Assumes coatings/minor retrofits; Savings based on mid-size vessel, specific fuel price & ops profile (ShipUniverse, 2025)	Shipyard capacity, Skills gap for advanced retrofits (Okorie, 2020)
Solar Panels (Auxiliary)	20,000–40,000^c^	Variable	7–15+^d^	5–10	Highly dependent on solar irradiation, fuel cost offset, installation complexity; Payback revised per (EnergySage, 2025; Theocharis et al., 2014)	High upfront cost perception, Financing (Donastorg et al., 2021)
Wind-Assist Propulsion	500,000 – 3,000,000^e^	~200,000+^f^	3–7+	15–20	Cost/Payback revised per (ShipUniverse, 2025) ; Savings depend heavily on vessel type, route, wind conditions	Very high upfront cost, Financing, Technical expertise (ShipUniverse, 2025; Donastorg et al., 2021)

LNG Transition	Infrastructure-dependent	200,000 +^g^	3–7+^h^	20–30	Savings based on fuel price differential (Perčić et al., 2023) ; Payback highly sensitive to prices & infra costs (IISD, 2024)	**Critical:** Lack of bunkering infrastructure, Stranded asset risk, Price volatility, Policy uncertainty (IISD, 2024; DNV, 2025)
Biofuel Transition	Engine/ Infra dependent	Variable	Variable	~30 (lifecycle dependent)	Savings depend on feedstock cost & availability; Lifecycle emissions vary (Carvalho et al., 2021)	Feedstock availability, Food security concerns, Policy gaps, Sustainability verification (Simonyan & Fasina, 2013; Ogunjobi et al., 2020)
Waste Heat Recovery System	50,000–100,000 ^i^	~72,000	2–4	5–8	Cost/Payback align generally with market reports (Market.us, 2025; Polaris Market Research, 2024) ; Suitable for larger vessels	Technical expertise for installation/maintenance (Okorie, 2020)

It should be noted that ^a^ Revised cost range reflects basic optimization; advanced systems cost more. ^b^ Savings highly variable based on vessel/operation. ^c^ Cost range adjusted slightly. ^d^ Payback significantly revised based on external data showing longer periods than initially suggested. ^e^ Cost significantly revised based on (ShipUniverse, 2025)(Hull,2025). ^f^ Savings dependent on scale/route. ^g^ Savings highly dependent on fuel price delta. ^h^ Payback adjusted, highly variable and risk-prone. ^i^ Cost range slightly adjusted based on market reports. All figures are indicative syntheses from literature and depend heavily on specific vessel, operation, market conditions (especially fuel prices), CO2 pricing, and policy support.The synthesized analysis

highlights that basic hull optimization measures (like coatings) offer the most attractive economics with potentially rapid payback periods (1–2 years)(Hull,2025) , making them a strong candidate for initial focus in Nigeria, provided shipyard capacity can be developed.

Renewable energy options (solar PV, wind-assist) show environmental promise but face significant economic hurdles based on current literature. The payback periods reported in external sources (7-15+ years for solar , 3-7+ years for wind-assist) are considerably longer than suggested in the original paper's abstract and Table 1. These technologies likely require substantial subsidies or innovative financing to be viable for most Nigerian operators, especially SMEs.(Salami,2020).

Alternative fuels (LNG, biofuels) represent potentially transformative long-term solutions but come with major caveats. LNG's viability is critically undermined by the lack of bunkering infrastructure in Nigeria and significant market/transition risks.(Radonja,2019). While potential savings exist [12], the required upfront investment (both vessel-side and port-side) is immense. Biofuels face sustainability, food security, and policy challenges specific to Nigeria.(Purnomo,2021). Their cost-benefit profile is highly dependent on feedstock choice and sustainable supply chain development.

Waste Heat Recovery Systems appear economically viable (2–4 year payback) for larger vessels based on market data , offering consistent fuel savings, but require technical expertise for implementation.(Palmetto,2021).

Overall, this synthesized cost-benefit review underscores that while green technologies offer potential economic and environmental advantages, their feasibility in Nigeria is not uniform. Simpler, lower-cost retrofits like basic hull optimization seem most immediately accessible. More advanced solutions, particularly renewables and alternative fuels, require significant investment, robust policy support, infrastructure development, and workforce upskilling to overcome substantial barriers. A phased approach, starting with readily achievable measures while strategically planning for longer-term transitions, seems most appropriate.

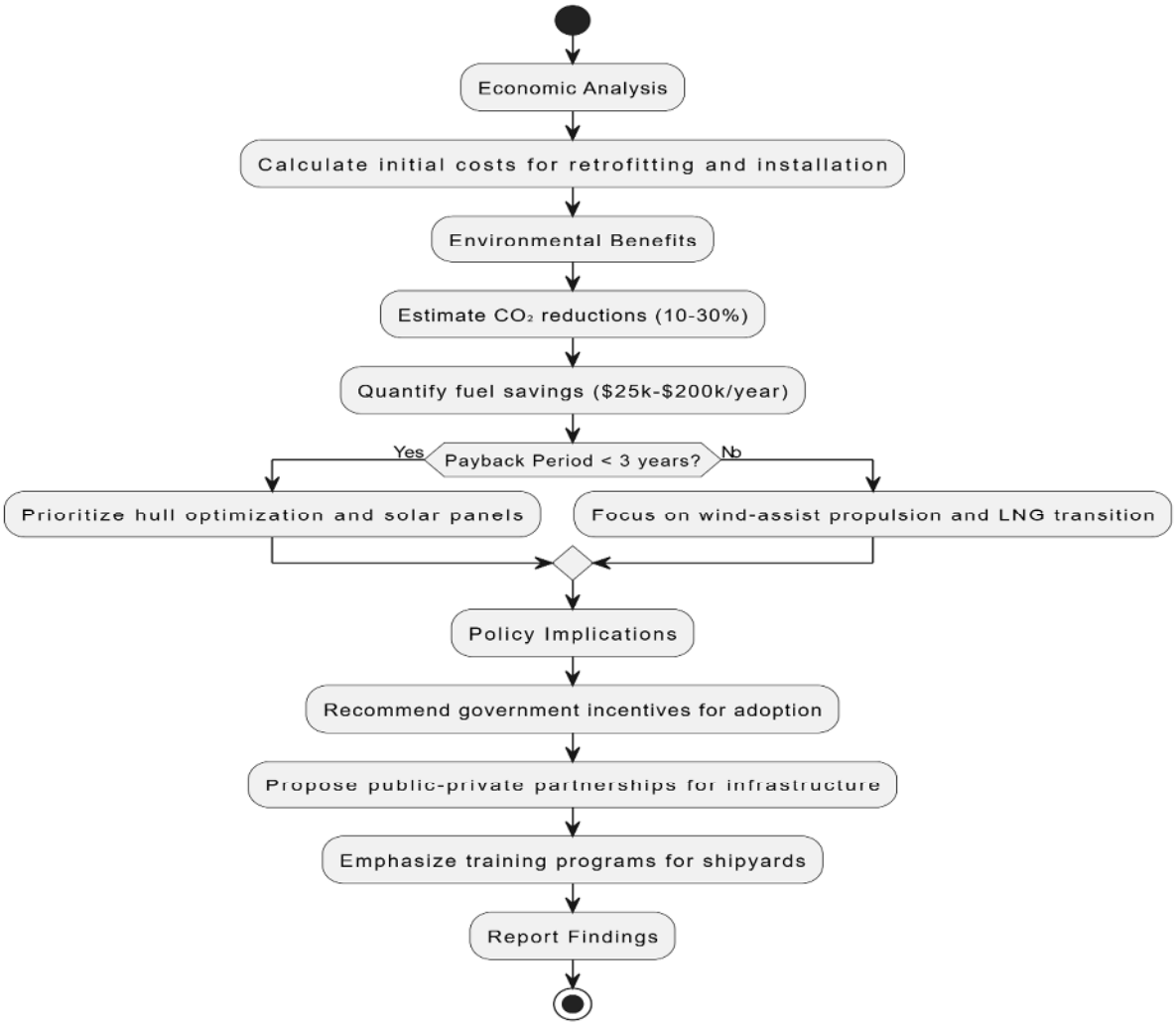


Figure 4: Synthesized Cost-Benefit Considerations for Green Ship Technologies in Nigeria.

5.0 CONCLUSION

This review indicates that the adoption of green ship technologies presents a viable, albeit challenging, pathway for Nigeria's maritime sector to enhance sustainability and align with global decarbonization goals, while potentially improving economic competitiveness. Based on a synthesis of existing literature, reports, and case studies, technologies such as hull optimization, renewable energy integration, alternative fuels (LNG and biofuels), and waste heat recovery

systems all offer varying degrees of potential for reducing fuel consumption and emissions within the Nigerian context.

Hull optimization, particularly through basic measures like low-friction coatings, emerges from the literature as a highly cost-effective initial step, offering significant fuel savings with relatively short payback periods. This makes it a practical starting point, especially for Nigeria's predominantly aging fleet, although successful implementation hinges on developing local shipyard capacity and skills. Renewable energy systems like solar PV and wind-assist propulsion offer long-term environmental benefits, but synthesized economic data suggests longer payback periods and higher upfront costs than sometimes assumed , necessitating strong policy incentives and financing solutions for widespread adoption in Nigeria.

The transition to alternative fuels like LNG and biofuels represents a more fundamental shift. While Nigeria possesses domestic resources (natural gas reserves, biomass potential) , significant hurdles impede progress. The lack of LNG bunkering infrastructure, coupled with market volatility and stranded asset risks, makes large-scale LNG adoption currently problematic. Biofuel development faces critical challenges related to food security, land use sustainability, and policy consistency. Waste heat recovery offers proven efficiency gains for larger vessels with reasonable payback times , but requires technical expertise.

Ultimately, this review underscores that realizing the potential of green shipping in Nigeria requires more than just identifying suitable technologies. It demands a concerted, strategic effort involving all stakeholders. Overcoming the critical barriers of inadequate infrastructure, significant skills gaps, policy inconsistencies, and financing constraints is paramount.[8] A phased approach, prioritizing accessible retrofits while investing in the necessary infrastructure, workforce development, and stable policy frameworks for longer-term solutions like alternative fuels, appears necessary. Through coordinated action and targeted investment, Nigeria can navigate the complexities of the green transition, fostering a more sustainable, resilient, and competitive maritime sector that contributes effectively to national development goals.

6.0 POLICY RECOMMENDATIONS

Based on the challenges identified and best practices reviewed in the literature, the successful implementation and scaling of green ship technologies in Nigeria necessitate a robust and supportive policy environment. The following recommendations are proposed:

1. **Develop Targeted Financial Incentives:** Implement specific subsidies, grants (especially for SMEs), low-interest loans, and tax breaks for shipowners investing in retrofitting existing vessels or acquiring new green technologies (Ebong, 2023; Donastorg et al., 2021). Consider differential port dues favoring vessels utilizing green technologies. These measures are crucial to overcome high upfront costs, a major barrier identified by stakeholders.
2. **Prioritize Strategic Infrastructure Investment:** Focus public and private investment, potentially through Public-Private Partnerships (PPPs) (UNCTAD, 2024; Donastorg et al., 2021) , on critical enabling infrastructure. This includes modernizing shipyards to handle advanced retrofits , establishing LNG bunkering facilities at key ports (if LNG risks are deemed manageable), deploying shore power systems , and potentially supporting sustainable biofuel production and supply chains.
3. **Invest Heavily in Capacity Building and Skills Development:** Address the critical skills gap by establishing dedicated training programs in collaboration with international organizations (like IMO) and industry partners (Okorie, 2020; Ebong, 2023). Update curricula at maritime training institutions to cover green technologies, operation, and maintenance. Strengthen existing initiatives like NIMASA's NSDP and foster mentorship programs.
4. **Strengthen Regulatory Framework and Enforcement:** Ensure clear, consistent, and long-term policies aligned with international standards (IMO 2023 GHG Strategy [5]) to build investor confidence (Ebong, 2023; Donastorg et al., 2021). Enhance the enforcement capacity of regulatory bodies like NIMASA to ensure compliance. Implement robust anti-corruption measures within the sector to foster transparency and fair competition. If pursuing biofuels, establish strict sustainability criteria and regulations to manage land use and food security risks.
5. **Promote Regional Collaboration:** Collaborate with neighboring countries in the Gulf of Guinea and broader African partners to develop harmonized regional standards, potentially

share infrastructure development costs (example, for bunkering), and pool resources for training and research (NIMASA, 2025). Participate actively in international forums (like IMO) to ensure Africa's interests are represented in global decarbonization policies.

6. **Foster Research, Development, and Awareness:** Support local research and development tailored to Nigeria's specific context. Launch awareness campaigns targeting shipowners, operators, and the public about the benefits and necessity of green shipping technologies (Ebong, 2023).

Implementing these recommendations requires strong political will, sustained investment, and effective collaboration between government agencies (Ministry of Marine and Blue Economy, NIMASA, NPA), industry stakeholders, financial institutions, and international partners.

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