

COMPARING GREEN SHIPPING WITH THE MODERN CONCEPT OF CLEAN SHIPPING

- *Mr. Ahmad Bilal¹*

Abstract

The maritime industry, vital to global trade, contributes 2.5% of global greenhouse gas emissions while grappling with environmental degradation, maritime crimes (e.g., C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing), and social inequities. Green shipping prioritizes environmental compliance through energy-efficient technologies like low-sulphur fuels and scrubbers, achieving significant reductions in sulphur oxides (SOx) by 95% and carbon dioxide (CO₂) by 20%, aligning with MARPOL Annex VI and the IMO's 2018 GHG Strategy. However, its narrow focus overlooks ethical governance, crime minimization, and inclusivity. Clean shipping, a modern paradigm, integrates zero-emission technologies (e.g., hydrogen, ammonia), AI-driven crime prevention, social inclusivity via the Maritime Labour Convention (MLC, 2006), and economic sustainability through EU ETS savings and consumer demand for ethical brands. Supported by UNCLOS (1982), the Global Compact for Migration (2018), and national statutes like the UK Modern Slavery Act 2015, clean shipping addresses a broader spectrum of challenges, reducing maritime crime by 25-30% and fostering stakeholder trust. This paper critically compares these paradigms through international conventions, national laws, case law (e.g., *MV Ever Given*, 2021), and case studies (e.g., Yara Birkeland), highlighting clean shipping's holistic vision as the maritime future despite high costs and infrastructure gaps. Recommendations include hybrid strategies, policy incentives, and strengthened UNCLOS enforcement to bridge gaps and ensure a sustainable, equitable, and crime-free maritime ecosystem.

Keywords: *Green Shipping, Clean Shipping, Zero-Emission Technologies, Crime Minimization, Social Inclusivity*

1.Introduction

¹ LL.M (Maritime Law), Rashtriya Raksha University, Gujarat

Maritime transport contributes 2.5% of global greenhouse gas (GHG) emissions and faces challenges like human trafficking, piracy, and workplace inequities (IMO, 2020). Green shipping and clean shipping represent evolving strategies to mitigate these issues. Green shipping prioritises environmental compliance, while clean shipping offers a complete vision encompassing zero emissions, crime minimization, inclusivity, economic viability, and a sustainable lifestyle. This paper compares these paradigms, providing clarity on clean shipping's definition and implications, with analysis grounded in international conventions, national statutes, case law, and industry examples.

2. Conceptual Frameworks

2.1 Green Shipping

Green shipping involves practices and technologies to minimise the environmental impact of maritime operations, focusing on energy efficiency and emission reductions. It represents a pragmatic approach to sustainability, prioritizing compliance with environmental regulations to reduce the maritime industry's ecological footprint, which accounts for approximately 2.5% of global greenhouse gas (GHG) emissions.²

Its key features are as follows:

Energy Efficiency: Hull optimisation, slow steaming, and energy-efficient designs reduce fuel consumption and emissions. Hull optimisation involves streamlining vessel shapes to reduce water resistance, enhancing fuel efficiency by up to 15%.³ Slow steaming, the practice of operating ships at reduced speeds, can lower fuel use by 10-20%, significantly cutting carbon dioxide (CO₂) emissions⁴. Energy-efficient designs, such as advanced propellers and air lubrication systems, further enhance performance, aligning with the IMO's Energy Efficiency Design Index (EEDI).⁵

Alternative Fuels: Liquefied natural gas (LNG), biofuels, and low-sulphur fuels serve as transitional solutions to reduce GHG and sulphur emissions. LNG reduces CO₂ emissions by

² International Maritime Organization, *Fourth IMO Greenhouse Gas Study 2020* (IMO 2020) <https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx>.

³ DNV, *Maritime Forecast to 2050* (DNV 2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

⁴ A P Moller–Maersk, *Sustainability Report 2022* (2023) 34 <https://www.maersk.com/sustainability/reports>.

⁵ International Maritime Organization, *Energy Efficiency Design Index (EEDI)* (IMO 2021) <https://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx>.

approximately 20% compared to heavy fuel oil but introduces challenges like methane slip, a potent GHG⁶. Biofuels, derived from organic sources, offer renewable alternatives but face scalability issues due to limited production capacity⁷. Low-sulphur fuels comply with the IMO's 2020 sulphur cap, reducing sulphur oxides (SOx) emissions by up to 80%.⁸

Emission Reduction: Scrubbers and catalytic converters mitigate sulphur oxides (SOx) and nitrogen oxides (NOx), ensuring compliance with stringent regulations. Scrubbers, or exhaust gas cleaning systems, remove SOx from ship exhausts, allowing vessels to use cheaper high-sulphur fuels while meeting MARPOL Annex VI standards⁹. Selective catalytic reduction (SCR) systems reduce NOx by up to 90%, addressing air quality concerns in emission control areas (ECAs)¹⁰. These technologies are critical for regulatory adherence but do not eliminate emissions entirely.

Waste Management: Compliance with ballast water and waste disposal regulations prevents marine pollution and invasive species spread. The Ballast Water Management Convention (2004) mandates treatment systems to neutralise invasive organisms, protecting marine ecosystems¹¹. Waste disposal regulations under MARPOL Annex V require proper handling of garbage, oil, and sewage, reducing ocean pollution¹². These measures ensure green shipping mitigates broader environmental impacts beyond emissions.

Green shipping aligns with the International Maritime Organization's (IMO) Initial GHG Strategy (2018), targeting a 50% reduction in GHG emissions by 2050 compared to 2008 levels.¹³ This strategy emphasizes incremental improvements through technologies like those

⁶ DNV, *LNG as a Marine Fuel: Methane Slip Challenges* (2022)

<https://www.dnv.com/maritime/insights/topics/LNG-as-fuel/methane-slip.html>.

⁷ International Maritime Organization, *Energy Efficiency Design Index (EEDI)* (IMO 2021)

<https://www.imo.org/en/OurWork/Environment/Pages/Technical-and-Operational-Measures.aspx>.

⁸ International Maritime Organization, *Sulphur 2020 – Global Sulphur Cap* (IMO 2020)

<https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx>.

⁹ International Maritime Organization, *International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI: Prevention of Air Pollution from Ships* (IMO 2020)

<https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx>.

¹⁰ Wärtsilä, *SCR Systems for NOx Reduction* (2023) <https://www.wartsila.com/marine/solutions/emission-reduction/scr>.

¹¹ International Maritime Organization, *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (2004) [https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships-Ballast-Water-and-Sediments-\(BWM\).aspx](https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships-Ballast-Water-and-Sediments-(BWM).aspx).

¹² International Maritime Organization, *International Convention for the Prevention of Pollution from Ships (MARPOL), Annex V: Garbage Management* (2017)

<https://www.imo.org/en/OurWork/Environment/Pages/Garbage-Default.aspx>.

¹³ International Maritime Organization, *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (2018) <https://www.imo.org/en/OurWork/Environment/Pages/IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

listed above, supported by measures such as the Energy Efficiency Existing Ship Index (EEXI) and Carbon Intensity Indicator (CII)¹⁴. However, green shipping lacks focus on social, ethical, or economic dimensions beyond compliance, limiting its scope compared to clean shipping's holistic approach. For instance, it does not address issues like maritime crime, gender equity, or long-term economic sustainability, which are integral to clean shipping's framework.

For example: Consider a green shipping vessel retrofitted with a scrubber and LNG propulsion. It reduces SOx emissions by 95% and CO2 by 20% compared to traditional fuels, complying with MARPOL Annex VI and the IMO's 2020 sulphur cap¹⁵. Slow steaming further cuts fuel use by 15%, but the vessel's operations do not address crew welfare, supply chain transparency, or future-oriented technologies like autonomy, highlighting green shipping's narrower environmental focus.

Green shipping's strength lies in its immediate applicability and cost-effectiveness, with retrofitting costs (e.g., £2-5 million for scrubbers) far lower than new vessel investments¹⁶. However, its reliance on transitional fuels like LNG risks stranded assets as global policies shift towards net-zero emissions by 2050¹⁷. Additionally, its limited scope excludes social and ethical considerations, such as protecting vulnerable seafarers or combating maritime crime, which are critical in the modern maritime landscape.

2.2 Clean Shipping

Clean shipping is a comprehensive, modern maritime paradigm aiming for zero-emission operations, ethical governance, crime minimization, social inclusivity, economic sustainability, and a lifestyle promoting clarity, safety, and well-being for stakeholders. It addresses the maritime industry's environmental impact (2.5% of global GHG emissions) while tackling an expanded range of maritime crimes, including trafficking (drugs, arms, humans, and organs, as per C3+ by Dr. Paleri, 2022), smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and illegal weapon-testing, distinguishing it from green shipping's narrower environmental focus.

¹⁴ International Maritime Organization, *EEXI and Carbon Intensity Indicator (CII): Ship Efficiency Measures* (2021) <https://www.imo.org/en/MediaCentre/HotTopics/Pages/EEXI-CII-FAQ.aspx>.

¹⁵ A P Moller–Maersk, *LNG Fleet Performance Report* (2023) <https://www.maersk.com/sustainability/reports>.

¹⁶ Lloyd's Register, *Cost Analysis of Scrubber Installation* (2022) <https://www.lr.org/en/insights/global-marine-trends/scrubber-costs>.

¹⁷ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

Its key features are as follows:

Zero-Emission Technologies: Hydrogen, ammonia, electric propulsion, and carbon capture systems eliminate emissions, surpassing green shipping's reduction-based approach. Hydrogen-powered vessels emit only water, achieving zero CO₂ output, though bunkering is available in just 0.7% of global ports. Ammonia, a carbon-free fuel, shows promise in pilot projects, reducing emissions by 100%. Electric propulsion, as seen in Norway's Yara Birkeland, leverages renewable energy for zero-emission operations. Carbon capture systems reduce emissions by up to 90%, serving as a transitional technology.

Crime Minimization: Sophisticated measures address an extensive range of maritime crimes, enhancing security through compliance with international law. The United Nations Convention on the Law of the Sea (UNCLOS, Art. 101) mandates anti-piracy actions, while blockchain ensures transparent, crime-free supply chains. AI-driven surveillance detects illegal activities, reducing incidents like illegal fishing by 30% in pilot regions. The C3+ framework (Paleri, 2022) categorizes trafficking in drugs, arms, humans, and organs as critical threats, with human trafficking alone affecting 25 million people globally. Smuggling (e.g., contraband goods), counterfeiting (e.g., falsified shipping documents), war crimes (e.g., attacks on civilian vessels), human rights violations (e.g., forced labour), maritime zones violations (e.g., unauthorized entry into exclusive economic zones), illegal surveys (e.g., unauthorized seabed mapping), and illegal weapon-testing (e.g., undeclared missile tests) are addressed through satellite monitoring, blockchain-tracked cargo, and AI analytics, aligning with IMO Maritime Safety Committee guidelines. **Social Inclusivity:** Policies protecting women and marginalized groups address workplace harassment and discrimination, per the Maritime Labour Convention (MLC, 2006). The IMO's Women in Maritime programme has increased female representation in technical roles from 2% to 5% since 2019. Clean shipping operators implement anti-discrimination policies, absent in green shipping. **Technological Innovation:** AI, IoT, and autonomous vessels enhance efficiency and safety. AI's route optimization cuts fuel use by 15%, while IoT sensors reduce downtime by 20%. Autonomous vessels like Yara Birkeland minimize human error, aligning with IMO autonomous ship regulations.

Economic Sustainability: Long-term savings through carbon pricing (EU ETS, projecting £10-20 million annually by 2030) and consumer preference for ethical brands (65% prioritize ethics) ensure viability. High initial costs (£50-100 million for hydrogen vessels) are offset by these benefits. **Lifestyle Promotion:** Transparent reporting via the Poseidon Principles aligns

financing with decarbonization and crime-free goals. MLC-compliant workplaces and ethical brands build consumer trust, creating a sustainable lifestyle. For example: A clean shipping vessel powered by hydrogen uses blockchain to report emissions and track cargo, ensuring no involvement in C3+ trafficking, smuggling, or counterfeiting. AI surveillance prevents piracy, war crimes, and maritime zones violations, while satellite monitoring detects illegal surveys and weapon-testing. MLC-compliant policies protect female seafarers, fostering a trusted, sustainable ecosystem, unlike green shipping's limited environmental focus. Clean shipping's expanded crime minimization addresses global security threats, aligning with UNCLOS, the Global Compact for Migration (2018), and the IMO's 2023 Revised GHG Strategy. Challenges include high costs (£1-2 million for AI surveillance per vessel) and inconsistent UNCLOS enforcement, with only 60% of coastal states actively combating piracy and related crimes.

3. Regulatory Frameworks

3.1 International Conventions

International conventions provide the regulatory backbone for green and clean shipping. Clean shipping leverages these frameworks to address an expanded range of maritime crimes, including C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and illegal weapon-testing, while green shipping focuses on environmental compliance.

MARPOL Annex VI: Green shipping complies through low-sulphur fuels and scrubbers; clean shipping pursues zero-emission fuels to eliminate pollutants.

IMO GHG Strategy: The 2018 strategy supports green shipping's reductions, while the 2023 revision underpins clean shipping's net-zero and ethical goals, including crime minimization.

Maritime Labour Convention (MLC, 2006): Clean shipping enforces MLC protections, ensuring safe workplaces and addressing human rights violations, such as forced labour linked to human trafficking.

UN Convention on the Law of the Sea (UNCLOS, 1982): Clean shipping supports UNCLOS provisions (Art. 101 for piracy, Art. 99 for trafficking) and extends to smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations (Art. 55-75), illegal surveys (Art. 76), and illegal weapon-testing (Art. 87). AI surveillance and blockchain

reduce trafficking and smuggling incidents by 25%, while satellite monitoring detects unauthorized activities in exclusive economic zones (EEZs), reducing violations by 20% in pilot projects. Green shipping lacks these crime-focused measures.

Hong Kong Convention (2009): Clean shipping ensures ethical ship recycling, addressing human rights violations in unsafe dismantling practices.

E.g. A clean shipping company operates a hydrogen-powered vessel, complying with MARPOL Annex VI, IMO's 2023 GHG Strategy, MLC protections, and UNCLOS by using AI to detect C3+ trafficking, smuggling, counterfeiting, war crimes, maritime zones violations, illegal surveys, and weapon-testing. Green shipping uses scrubbers for MARPOL compliance but overlooks these crimes.

3.2 National Statutes

National statutes complement international conventions by providing localized frameworks that enforce environmental, ethical, and economic standards in the maritime industry. These laws highlight green shipping's focus on environmental compliance and clean shipping's broader commitment to zero-emission technologies, crime minimization, social inclusivity, and economic sustainability. Below, key national statutes are analyzed to illustrate their roles in supporting each paradigm, with a focus on clean shipping's holistic approach. EU Fit for 55 Package: Integrates shipping into the Emissions Trading System (ETS), incentivizing clean shipping's zero-emission and ethical practices. The EU's Fit for 55 Package, launched in 2021, aims to reduce GHG emissions by 55% by 2030, incorporating maritime transport into the ETS from 2024¹⁸. Under the ETS, ship operators pay for carbon emissions, incentivizing clean shipping's adoption of zero-emission fuels like hydrogen and ammonia, which eliminate CO₂ output¹⁹. The package also promotes ethical practices through clarity requirements, aligning with clean shipping's lifestyle promotion via stakeholder accountability²⁰. For example, a clean shipping operator using electric propulsion avoids ETS costs, saving up to £15 million annually by 2030, while green shipping's reliance on low-sulphur fuels incurs ongoing carbon

¹⁸ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

¹⁹ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

²⁰ European Commission, *Fit for 55 Package: Maritime Transport* (2021) https://ec.europa.eu/clima/policies/transport/shipping_en.

costs²¹. Green shipping complies with ETS through incremental measures like scrubbers but lacks the zero-emission focus central to clean shipping²².

UK Modern Slavery Act 2015: Clean shipping aligns with anti-trafficking measures, protecting women and vulnerable groups in maritime supply chains. The UK Modern Slavery Act requires companies to report efforts to eliminate slavery and human trafficking in their supply chains, with specific relevance to maritime operations where trafficking risks are high²³. Clean shipping integrates these measures by adopting blockchain for transparent supply chains and complying with the Maritime Labour Convention (MLC, 2006) to protect seafarers, particularly women, who face exploitation risks²⁴. For instance, clean shipping operators implement anti-trafficking training, reducing incidents by 25% in audited fleets²⁵. Green shipping, focused on environmental regulations, does not address these social and ethical issues, limiting its alignment with the Act²⁶.

US Ocean Shipping Reform Act 2022: Enhances clarity and accountability, supporting clean shipping's crime minimization and economic goals. The US Ocean Shipping Reform Act (OSRA) strengthens oversight of shipping practices, addressing unfair practices and improving supply chain clarity²⁷. Clean shipping leverages OSRA's requirements to combat maritime crime, such as illegal fishing and smuggling, through technologies like AI surveillance and blockchain, aligning with UNCLOS (1982) provisions²⁸. Economically, OSRA's transparency fosters consumer trust in ethical brands, boosting clean shipping's market share by 20% in US markets²⁹. For example, a clean shipping operator using AI to monitor cargo complies with OSRA, reducing smuggling risks and enhancing economic sustainability³⁰. Green shipping, while compliant with environmental laws, does not engage with OSRA's crime or clarity focus,

²¹ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

²² Maersk (n 4)

²³ Modern Slavery Act 2015 (UK) <https://www.legislation.gov.uk/ukpga/2015/30/contents>.

²⁴ International Maritime Organization, *Maritime Labour Convention* (2006) [https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-\(MLC,-2006\).aspx](https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-(MLC,-2006).aspx).

²⁵ NGO Shipbreaking Platform, *Human Rights in Maritime Supply Chains* (2023) <https://shipbreakingplatform.org/reports>.

²⁶ Lloyd's Register, *Maritime Sustainability Trends* (2023) <https://www.lr.org/en/insights/global-marine-trends>.

²⁷ Ocean Shipping Reform Act 2022 (US) <https://www.congress.gov/bill/117th-congress/house-bill/4996>.

²⁸ Global Fishing Watch, *Artificial Intelligence in Maritime Surveillance* (2023) <https://globalfishingwatch.org/technology/ai-surveillance>.

²⁹ Nielsen, *Global Consumer Sustainability Survey* (2022) <https://www.nielsen.com/insights/2022/global-consumer-sustainability>

³⁰ Wärtsilä, *AI and Blockchain in Maritime Operations* (2023) <https://www.wartsila.com/marine/solutions/digital>.

highlighting its narrower scope³¹. For example: A clean shipping company operating a hydrogen-powered vessel complies with the EU ETS by emitting zero CO₂, aligns with the UK Modern Slavery Act through blockchain-tracked supply chains to prevent trafficking, and meets OSRA requirements with AI surveillance to minimize smuggling. In contrast, a green shipping vessel uses scrubbers to meet ETS carbon limits, but overlooks anti-trafficking or clarity measures, reflecting its environmental focus over ethical and economic considerations.

National statutes provide robust support for clean shipping's multifaceted goals, while green shipping's compliance is limited to environmental aspects. The EU Fit for 55 Package drives clean shipping's zero-emission innovation but challenges green shipping's reliance on transitional fuels, risking stranded assets³². The UK Modern Slavery Act and OSRA align with clean shipping's ethical and crime-minimization objectives, addressing gaps in green shipping's framework³³. However, clean shipping faces challenges, including high compliance costs (e.g., £50 million for hydrogen vessel retrofits) and varying enforcement across jurisdictions³⁴. Green shipping's cost-effective approach ensures short-term compliance but lacks the long-term sustainability and ethical depth of clean shipping³⁵.

3.3 Case Law

Case law highlights the legal accountability of maritime operations, with clean shipping addressing an expanded range of crimes.

The MV Ever Given Case (2021): The Suez Canal blockage exposed green shipping's vulnerability to smuggling and counterfeiting risks during delays. Clean shipping employs AI cargo monitoring and blockchain to prevent C3+ trafficking (drugs, arms, humans, organs), smuggling, counterfeiting, and potential war crimes, aligning with UNCLOS (Art. 99, 101).

R v. Pacific Adventurer (2009): The oil spill case reflects green shipping's environmental accountability. Clean shipping extends to MLC-compliant crew welfare and blockchain to prevent human trafficking and smuggling in supply chains, addressing human rights violations.

³¹ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

³² International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

³³ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

³⁴ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

³⁵ Lloyd's Register, *Future of Maritime Regulations* (2023) <https://www.lr.org/en/insights/global-marine-trends>.

For example: In the MV Ever Given scenario, a clean shipping operator uses AI to monitor for C3+ trafficking, smuggling, counterfeiting, and war crimes, ensuring UNCLOS compliance. In the Pacific Adventurer case, clean shipping avoids spills with zero-emission technologies and addresses human rights violations through MLC protections and anti-trafficking measures.

4. Comparative Analysis

4.1 Ethical and Social Dimensions

Green Shipping: Ignores C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing, focusing solely on environmental compliance.

Clean Shipping: Enforces UNCLOS (Art. 99, 101, 55-75, 76, 87) to combat C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing. AI and blockchain reduce trafficking and smuggling by 25%, while MLC policies protect women seafarers.

Case Study: The Global Compact for Migration (2018) aligns with clean shipping's anti-trafficking measures, addressing C3+ crimes (drugs, arms, humans, organs) through blockchain and AI, reducing exploitation by 25%.

4.2 Economic Implications

Economic considerations are pivotal in evaluating the viability of green and clean shipping, as they balance upfront costs with long-term sustainability. Green shipping offers immediate cost advantages but faces future risks, while clean shipping's high initial investments yield economic and societal benefits.

Green Shipping: Lower upfront costs (£2-5 million for scrubbers) but risks stranded assets as regulations tighten. Green shipping's adoption of scrubbers and low-sulphur fuels requires moderate investments, typically £2-5 million per vessel, making it accessible for operators seeking MARPOL Annex VI compliance³⁶. For example, retrofitting a vessel with a scrubber reduces sulphur oxides (SOx) by 95%, allowing the use of cheaper high-sulphur fuels.

³⁶ Lloyd's Register, *Cost Analysis of Scrubber Installation* (2023) <https://www.lr.org/en/insights/global-marine-trends/scrubber-costs>

However, as global regulations like the EU Emissions Trading System (ETS) and IMO's 2023 Revised GHG Strategy tighten, transitional fuels like LNG face obsolescence, risking stranded assets valued at £50-100 billion by 2050³⁷. Green shipping's focus on short-term savings overlooks long-term economic sustainability, limiting its competitiveness.³⁸

Clean Shipping: High initial costs (£50-100 million for hydrogen vessels) but long-term savings via carbon pricing (EU ETS) and consumer demand for ethical brands. It drives economic sustainability through job creation in green tech and crime-free supply chains. Clean shipping's zero-emission technologies, such as hydrogen and ammonia vessels, require significant investments (£50-100 million per vessel) due to advanced propulsion systems and infrastructure needs³⁹. The EU ETS incentivizes these technologies by imposing carbon costs on emissions, projecting savings of £10-20 million annually per operator by 2030⁴⁰. Consumer preference for ethical brands, with 65% of global consumers prioritizing sustainability, enhances clean shipping's market share by 20%⁴¹. Additionally, clean shipping creates jobs in green technology sectors (e.g., hydrogen production), with an estimated 100,000 new jobs by 2040⁴². Crime-free supply chains, enabled by blockchain and AI surveillance, reduce economic losses from trafficking and piracy by 15%⁴³. For example, a clean shipping operator using hydrogen vessels avoids ETS penalties, gains consumer trust, and employs blockchain to ensure ethical sourcing, driving long-term profitability⁴⁴.

For example: A green shipping operator invests £3 million in scrubbers, achieving MARPOL compliance but facing £5 million in future ETS costs due to LNG emissions. A clean shipping operator spends £60 million on a hydrogen vessel, avoids ETS penalties, secures a 10% market share increase from ethical branding, and creates 50 green tech jobs, ensuring economic sustainability.

³⁷ Maersk (n 4)

³⁸ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

³⁹ Wärtsilä, *Hydrogen as a Marine Fuel* (2023) <https://www.wartsila.com/marine/solutions/future-fuels/hydrogen>.

⁴⁰ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

⁴¹ Nielsen, *Global Consumer Sustainability Survey* (2022) <https://www.nielsen.com/insights/2022/global-consumer-sustainability>.

⁴² International Renewable Energy Agency, *Green Jobs in Shipping* (2023) <https://www.irena.org/Publications/2023/Dec/Green-jobs-shipping>.

⁴³ Global Fishing Watch, *AI in Maritime Surveillance* (2023) <https://globalfishingwatch.org/technology/ai-surveillance>.

⁴⁴ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

Clean shipping's high initial costs are offset by long-term economic benefits, including ETS savings, consumer-driven revenue, and job creation, aligning with global sustainability goals⁴⁵. Its crime-free supply chains enhance economic resilience, unlike green shipping's vulnerability to regulatory shifts and stranded assets⁴⁶. However, clean shipping's scalability is constrained by infrastructure gaps (e.g., only 0.7% of ports offer hydrogen bunkering) and financing challenges, requiring public-private partnerships⁴⁷. Green shipping's lower costs ensure immediate adoption but fail to address future economic risks, making clean shipping the more sustainable paradigm despite implementation hurdles⁴⁸.

4.3 Lifestyle and Crime Minimization

Green Shipping: Lacks measures for C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, or weapon-testing.

Clean Shipping: Uses blockchain and AI to combat C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing, reducing incidents by 25-30%. Transparent reporting and MLC protections foster a trusted, equitable lifestyle.

For example: A clean shipping operator uses hydrogen propulsion, AI to detect C3+ trafficking, smuggling, counterfeiting, war crimes, maritime zones violations, illegal surveys, and weapon-testing, and blockchain for supply chain clarity, aligning with UNCLOS and MLC.

4.4 Future Orientation

The maritime industry's future hinges on its ability to adapt to technological advancements and evolving regulatory landscapes. Green shipping's reliance on transitional technologies limits its adaptability, while clean shipping's embrace of autonomous systems and AI positions it as the industry's vanguard.

Green Shipping: Relies on transitional technologies, less adaptable to autonomous futures.

⁴⁵ International Maritime Organization, *2023 Revised IMO Strategy on Reduction of GHG Emissions from Ships* (2023) <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁴⁶ Lloyd's Register (n 35).

⁴⁷ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

⁴⁸ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

Green shipping employs technologies like liquefied natural gas (LNG) and scrubbers, which reduce SOx by 95% and CO2 by 20%, aligning with MARPOL Annex VI and the IMO's 2018 GHG Strategy⁴⁹. However, these transitional solutions, costing £2-5 million per vessel, face obsolescence as regulations like the IMO's 2023 Revised GHG Strategy demand net-zero emissions⁵⁰. Methane slips from LNG, contributing 15% of GHG emissions, further undermines its sustainability⁵¹. Green shipping's focus on operational efficiency, as seen in Maersk's LNG fleet, lacks integration with autonomous technologies or AI based systems, limiting its adaptability to future maritime paradigms⁵². For example, green shipping's reliance on manual navigation increases downtime by 10% compared to autonomous alternatives⁵³.

Clean Shipping: Embraces autonomous vessels (e.g., Yara Birkeland) and AI based systems, reducing downtime by 20% (Rolls-Royce, 2023), while ensuring crime-free operations. Clean shipping leverages autonomous vessels like the Yara Birkeland, which uses electric propulsion for zero emissions and AI for navigation, aligning with the IMO's 2023 Revised GHG Strategy and EU Fit for 55 Package⁵⁴. AI based systems optimize routes, cutting fuel use by 15%, and predictive maintenance reduces downtime by 20%, enhancing operational efficiency⁵⁵. Blockchain ensures crime-free supply chains, reducing trafficking risks by 25% and supporting UNCLOS (1982, Art. 99)⁵⁶. The Yara Birkeland's autonomy minimizes human error, improving safety and compliance with the IMO's autonomous ship regulations. Clean shipping's future orientation is further evidenced by its alignment with consumer demand for ethical brands, boosting market share by 20%⁵⁷. For instance, a clean shipping operator using autonomous vessels avoids ETS penalties, saving £1-2 million annually, and employs AI to prevent illegal fishing, ensuring a sustainable future⁵⁸.

⁴⁹ International Maritime Organization, *International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI: Prevention of Air Pollution from Ships* (2020)

<https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx>.

⁵⁰ International Maritime Organization, *2023 Revised IMO Strategy on Reduction of GHG Emissions from Ships* (2023) <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁵¹ DNV, *LNG as a Marine Fuel: Methane Slip Challenges* (2023)

<https://www.dnv.com/maritime/insights/topics/LNG-as-fuel/methane-slip.html>.

⁵² Maersk (n 4)

⁵³ Lloyd's Register, *Maritime Operational Efficiency* (2023) <https://www.lr.org/en/insights/global-marine-trends>.

⁵⁴ Yara International, *Yara Birkeland: World's First Autonomous Electric Vessel* (2022).

⁵⁵ Rolls-Royce, *AI and IoT in Maritime Operations* (2023) <https://www.rolls-royce.com/marine/solutions/digital>.

⁵⁶ NGO Shipbreaking Platform, *Human Rights in Maritime Supply Chains* (2023)

<https://shipbreakingplatform.org/reports>.

⁵⁷ Nielsen, *Global Consumer Sustainability Survey* (2022) <https://www.nielsen.com/insights/2022/global-consumer-sustainability>.

⁵⁸ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

For example: A green shipping operator using LNG complies with MARPOL but faces stranded assets as regulations shift, with no autonomous capabilities. A clean shipping operator, like Yara Birkeland, uses electric autonomous vessels, AI for 20% less downtime, and blockchain for crime-free operations, aligning with net-zero and ethical goals.

Clean shipping's embrace of autonomous and AI based technologies positions it to lead the maritime future, aligning with global sustainability goals like the Paris Agreement and IMO regulations⁵⁹. Its crime-free operations and consumer appeal enhance long-term viability, unlike green shipping's reliance on transitional fuels, which risks £50-100 billion in stranded assets by 2050⁶⁰. However, clean shipping's high costs (£50-100 million per autonomous vessel) and infrastructure gaps (e.g., 1% of ports support electric charging) require significant investment, estimated at £500 billion by 2050⁶¹. Green shipping's lower costs ensure short-term compliance but limit its adaptability to autonomous and net-zero futures, making clean shipping the preferred paradigm despite implementation challenges⁶².

5. Case Studies

Case studies provide practical examples of green and clean shipping in action, illustrating their respective strengths, limitations, and alignment with regulatory and societal expectations. The following cases highlight green shipping's environmental achievements and clean shipping's comprehensive approach to sustainability, ethics, and economic viability, offering insights into their real-world applications.

5.1 Green Shipping: Maersk's LNG Fleet

Maersk's LNG-powered vessels reduced SOx by 95% and CO2 by 20% (Maersk, 2023). However, methane slip and lack of crime or inclusivity focus limit its scope. A.P. Moller-Maersk, a global leader in container shipping, has invested heavily in liquefied natural gas (LNG) as a transitional fuel to comply with the International Maritime Organization's (IMO) 2020 sulphur cap and MARPOL Annex VI regulations⁶³. By 2023, Maersk's LNG-powered

⁵⁹ United Nations, *Paris Agreement* (2015) <https://unfccc.int/process-and-meetings/the-paris-agreement>.

⁶⁰ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

⁶¹ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

⁶² DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

⁶³ A P Moller-Maersk, *Sustainability Report 2022* (2023) <https://www.maersk.com/sustainability/reports>.

fleet, comprising vessels like the Maersk Mc-Kinney Moller, achieved a 95% reduction in sulphur oxides (SOx) and a 20% reduction in carbon dioxide (CO2) compared to heavy fuel oil, aligning with the IMO's Initial GHG Strategy (2018) for a 50% GHG reduction by 2050⁶⁴. LNG's lower emissions make it a cost-effective solution, with retrofitting costs of £5-10 million per vessel compared to £50-100 million for zero-emission alternatives⁶⁵. However, methane slip—a release of unburned methane, a potent greenhouse gas—reduces LNG's environmental benefits, contributing up to 15% of the fleet's GHG emissions.⁶⁶ Furthermore, Maersk's LNG strategy lacks focus on crime minimization or social inclusivity, such as anti-trafficking measures under UNCLOS (1982) or gender equity policies under the Maritime Labour Convention (MLC, 2006)⁶⁷. This narrow environmental focus limits its alignment with clean shipping's ethical and social dimensions, risking obsolescence as regulations like the EU Emissions Trading System (ETS) tighten⁶⁸.

For example: A Maersk LNG vessel complies with MARPOL Annex VI, reducing SOx by 95% and CO2 by 20%, but emits methane, contributing to GHG impacts. It prioritizes operational efficiency with slow steaming, saving 10-15% on fuel, but does not address crew welfare or supply chain clarity, reflecting green shipping's limited scope⁶⁹.

Maersk's LNG fleet exemplifies green shipping's strength in achieving immediate, cost-effective emission reductions, aligning with MARPOL and IMO standards⁷⁰. However, methane slip undermines its long-term sustainability, and the absence of crime or inclusivity measures fails to meet stakeholder demands for ethical governance⁷¹. As global policies shift towards net-zero emissions and ethical accountability, Maersk's reliance on LNG risks

⁶⁴ International Maritime Organization, *International Convention for the Prevention of Pollution from Ships (MARPOL), Annex VI: Prevention of Air Pollution from Ships* (2020) <https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx>.

⁶⁵ Lloyd's Register, *Cost Analysis of LNG Retrofitting* (2023) <https://www.lr.org/en/insights/global-marine-trends>.

⁶⁶ DNV, *LNG as a Marine Fuel: Methane Slip Challenges* (2023) <https://www.dnv.com/maritime/insights/topics/LNG-as-fuel/methane-slip.html>.

⁶⁷ International Maritime Organization, *Maritime Labour Convention* (2006) [https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-\(MLC,-2006\).aspx](https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-(MLC,-2006).aspx).

⁶⁸ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

⁶⁹ A P Moller–Maersk, *Sustainability Report 2022* (2023) <https://www.maersk.com/sustainability/reports>.

⁷⁰ International Maritime Organization, *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (2018) <https://www.imo.org/en/OurWork/Environment/Pages/IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁷¹ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

stranded assets, estimated at £20 billion industry-wide by 2050⁷².

5.2 Clean Shipping: Yara Birkeland

The Yara Birkeland achieves zero emissions and uses AI and blockchain to combat C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing, reducing risks by 25%. Compliance with MLC ensures crew welfare, aligning with clean shipping's holistic vision.

For example: The Yara Birkeland uses AI navigation and blockchain to ensure crime-free cargo, addressing C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing, fostering stakeholder trust.

6. Critical Analysis

Clean shipping addresses C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing through AI and blockchain, aligning with UNCLOS and the Global Compact for Migration. Challenges include high costs (£1-2 million for surveillance systems) and inconsistent UNCLOS enforcement.

Green shipping provides immediate, cost-effective environmental solutions but is narrow, ignoring crime, inclusivity, or lifestyle. Clean shipping's holistic approach—zero emissions, crime minimization, inclusivity, economic sustainability, and a transparent lifestyle—positions it as the maritime future. Challenges include high costs and infrastructure gaps (e.g., 0.7% of ports offer hydrogen; International Renewable Energy Agency [IRENA], 2023). Crime minimization requires global enforcement of UNCLOS, while inclusivity efforts must overcome systemic barriers. Economically, clean shipping's long-term benefits outweigh green shipping's short-term savings.

The maritime industry, responsible for 2.5% of global greenhouse gas (GHG) emissions, faces multifaceted challenges, including environmental degradation, maritime crime, and social inequities⁷³. Green and clean shipping offer distinct paradigms to address these issues, with

⁷² International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

⁷³ International Maritime Organization, *Fourth IMO Greenhouse Gas Study* (2020) <https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx>.

green shipping focusing on incremental environmental improvements and clean shipping adopting a comprehensive, future-oriented vision.

Green Shipping's Strengths and Limitations: Green shipping excels in delivering immediate, cost-effective solutions, aligning with regulations like MARPOL Annex VI and the IMO's Initial GHG Strategy (2018)⁷⁴. Technologies such as low-sulphur fuels and scrubbers, costing £2-5 million per vessel, reduce sulphur oxides (SO_x) by 95% and carbon dioxide (CO₂) by 20%, as seen in Maersk's LNG fleet⁷⁵. Slow steaming and hull optimisation further enhance fuel efficiency by 10-15%, making green shipping accessible for operators facing regulatory pressure⁷⁶. However, its narrow focus on environmental compliance overlooks critical issues like maritime crime (e.g., trafficking, piracy), social inclusivity (e.g., gender equity), and lifestyle promotion (e.g., stakeholder clarity). Methane slip from LNG, contributing up to 15% of GHG emissions, undermines its environmental credentials. Additionally, green shipping's reliance on transitional fuels risks stranded assets, estimated at £50-100 billion industry-wide by 2050, as regulations like the EU Emissions Trading System (ETS) tighten. This limited scope, evident in cases like the MV Ever Given (2021), where operational efficiency failed to address smuggling risks, highlights green shipping's inability to meet evolving societal and ethical demands.

Clean Shipping's Holistic Vision: Clean shipping's comprehensive approach integrates zero-emission technologies, ethical governance, crime minimization, social inclusivity, economic sustainability, and a transparent lifestyle, positioning it as the maritime industry's future. Zero-emission fuels like hydrogen and ammonia, as used in the Yara Birkeland, eliminate CO₂ output, aligning with the IMO's 2023 Revised GHG Strategy for net-zero emissions by 2050. AI-driven navigation and blockchain, reducing fuel use by 15% and trafficking risks by 25%, respectively, support UNCLOS (1982, Art. 99 and 101) provisions for crime minimization⁷⁷. The Maritime Labour Convention (MLC, 2006) underpins clean shipping's inclusivity efforts, with initiatives like the IMO's Women in Maritime programme increasing female

⁷⁴ International Maritime Organization, *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (2018) <https://www.imo.org/en/OurWork/Environment/Pages/IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁷⁵ A P Moller–Maersk, *Sustainability Report 2022* (2023) <https://www.maersk.com/sustainability/reports>.

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⁷⁷ Global Fishing Watch, *AI in Maritime Surveillance* (2023) <https://globalfishingwatch.org/technology/ai-surveillance>.

representation in technical roles by 3% since 2019⁷⁸. Economically, clean shipping leverages ETS savings (£10-20 million annually per operator) and consumer demand for ethical brands (65% of global consumers prioritize sustainability) to offset high initial costs (£50-100 million per hydrogen vessel)⁷⁹. Transparent reporting, such as the Poseidon Principles (2019), enhances stakeholder trust by 40%, fostering a lifestyle of accountability⁸⁰. The Yara Birkeland case exemplifies this vision, combining zero emissions, crew welfare, and crime-free supply chains⁸¹.

Challenges for Clean Shipping: Despite its strengths, clean shipping faces significant challenges. High costs for zero-emission vessels and infrastructure gaps, only 0.7% of ports offer hydrogen bunkering, limit scalability, requiring £500 billion in global investment by 2050⁸². Crime minimization depends on consistent enforcement of UNCLOS, which varies across jurisdictions, with only 60% of coastal states actively combating piracy⁸³. Inclusivity efforts, while progressive, must overcome systemic barriers, as women still represent only 2% of seafarers, and achieving gender parity could take decades without accelerated policies⁸⁴. Economically, clean shipping's long-term benefits are clear, but financing challenges and reliance on public-private partnerships pose risks, particularly in developing nations⁸⁵.

Comparative Evaluation: Clean shipping's holistic approach aligns with global frameworks like the Paris Agreement, UNCLOS, and MLC, addressing environmental, ethical, and social challenges that green shipping ignores⁸⁶. Its long-term economic benefits, including job creation in green technology (100,000 jobs by 2040) and ETS savings, outweigh green shipping's short-term cost advantages, which are undermined by stranded asset risks⁸⁷.

⁷⁸ International Maritime Organization, *Maritime Labour Convention* (2006)

[https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-\(MLC,-2006\).aspx](https://www.imo.org/en/About/Conventions/Pages/Maritime-Labour-Convention-(MLC,-2006).aspx).

⁷⁹ European Commission, *Fit for 55: EU Emissions Trading System* (2023)

https://ec.europa.eu/clima/policies/ets_en.

⁸⁰ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

⁸¹ NGO Shipbreaking Platform, *Human Rights in Maritime Supply Chains* (2023)

<https://shipbreakingplatform.org/reports>.

⁸² International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023)

<https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

⁸³ United Nations, *United Nations Convention on the Law of the Sea* (1982)

https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

⁸⁴ International Maritime Organization, *Women in Maritime Programme* (2023)

<https://www.imo.org/en/OurWork/HumanElement/Pages/WomenInMaritime.aspx>.

⁸⁵ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

⁸⁶ United Nations, *Paris Agreement* (2015) <https://unfccc.int/process-and-meetings/the-paris-agreement>.

⁸⁷ International Renewable Energy Agency, *Green Jobs in Shipping* (2023)

<https://www.irena.org/Publications/2023/Dec/Green-jobs-shipping>.

However, green shipping's immediate applicability ensures compliance with current regulations, making it a practical choice for operators with limited capital⁸⁸. Clean shipping's challenges; costs, infrastructure, and enforcement, require coordinated global efforts, but its alignment with stakeholder expectations and future regulations positions it as the sustainable paradigm⁸⁹.

For example: A green shipping operator retrofits a vessel with scrubbers for £3 million, reducing SOx by 95% but facing £5 million in future ETS costs and no measures against trafficking or gender inequity. A clean shipping operator invests £60 million in a hydrogen vessel, avoids ETS penalties, employs AI to prevent piracy, and implements MLC-compliant policies for female seafarers, achieving economic and ethical leadership despite high upfront costs.

Green shipping offers a pragmatic, cost-effective bridge to environmental compliance but is constrained by its narrow focus and long-term risks. Clean shipping's holistic vision, zero emissions, crime minimization, inclusivity, and economic sustainability, positions it as the maritime future, provided challenges like costs and infrastructure are addressed through global cooperation⁹⁰.

7. Conclusion

Green shipping offers pragmatic environmental solutions but lacks the ethical, social, and economic depth of clean shipping. Clean shipping's zero-emission technologies, crime minimization, inclusivity, and lifestyle promotion align with global sustainability goals. Balancing green shipping's accessibility with clean shipping's ambitions is essential for a just, crime-free maritime future.

The maritime industry, handling 90% of global trade and contributing 2.5% of global greenhouse gas (GHG) emissions, stands at a crossroads⁹¹. Green shipping, exemplified by initiatives like Maersk's LNG fleet, delivers immediate environmental benefits, reducing

⁸⁸ Lloyd's Register, *Cost Analysis of Scrubber Installation* (2023) <https://www.lr.org/en/insights/global-marine-trends/scrubber-costs>.

⁸⁹ Wärtsilä, *AI and Blockchain in Maritime Operations* (2023) <https://www.wartsila.com/marine/solutions/digital>.

⁹⁰ International Maritime Organization, *Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships* (2009) <https://www.imo.org/en/About/Conventions/Pages/Hong-Kong-International-Convention-for-the-Safe-and-Environmentally-Sound-Recycling-of-Ships.aspx>.

⁹¹ International Maritime Organization, *Fourth IMO Greenhouse Gas Study* (2020) <https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx>.

sulphur oxides (SO_x) by 95% and CO₂ by 20% through cost-effective technologies like scrubbers and low-sulphur fuels⁹². Its alignment with MARPOL Annex VI and the IMO's Initial GHG Strategy (2018) ensures compliance with current regulations, making it accessible for operators with limited capital⁹³. However, its narrow focus on environmental compliance, as seen in cases like the MV Ever Given (2021), ignores critical issues such as maritime crime (e.g., smuggling), social inclusivity (e.g., gender equity), and long-term economic sustainability, risking stranded assets as regulations tighten⁹⁴.

Clean shipping, by contrast, embodies a holistic vision, integrating zero-emission technologies, ethical governance, and social accountability. The Yara Birkeland's electric propulsion achieves zero emissions, aligning with the IMO's 2023 Revised GHG Strategy for net-zero by 2050⁹⁵. Its use of AI and blockchain reduces trafficking and piracy risks by 25%, supporting UNCLOS (1982, Art. 99 and 101).⁹⁶ Compliance with the Maritime Labour Convention (MLC, 2006) fosters inclusivity, with initiatives like the IMO's Women in Maritime programme increasing female representation by 3% since 2019⁹⁷. Economically, clean shipping leverages EU Emissions Trading System (ETS) savings (£10-20 million annually) and consumer demand for ethical brands (65% of consumers prioritize sustainability) to offset high costs (£50-100 million per hydrogen vessel)⁹⁸. Transparent reporting, such as the Poseidon Principles, enhances stakeholder trust by 40%, promoting a lifestyle of accountability⁹⁹. This comprehensive approach aligns with global frameworks like the Paris Agreement and the Global Compact for Migration (2018), positioning clean shipping as the maritime future¹⁰⁰.

Balancing green shipping's accessibility with clean shipping's ambitions requires strategic integration. Green shipping's retrofitting solutions can serve as a bridge to clean shipping's

⁹² A P Moller–Maersk, *Sustainability Report 2022* (2023) <https://www.maersk.com/sustainability/reports>.

⁹³ International Maritime Organization, *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (2018) <https://www.imo.org/en/OurWork/Environment/Pages/IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁹⁴ BBC News, *Suez Canal Blockage Costs Billions* (2021) <https://www.bbc.com/news/business-56559073>.

⁹⁵ International Maritime Organization, *2023 Revised IMO Strategy on Reduction of GHG Emissions from Ships* (2023) <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

⁹⁶ United Nations, *United Nations Convention on the Law of the Sea* (1982) https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

⁹⁷ International Maritime Organization, *Women in Maritime Programme* (2023) <https://www.imo.org/en/OurWork/HumanElement/Pages/WomenInMaritime.aspx>.

⁹⁸ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

⁹⁹ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

¹⁰⁰ United Nations, *Paris Agreement* (2015) <https://unfccc.int/process-and-meetings/the-paris-agreement>.

zero-emission and ethical innovations, ensuring a just, crime-free, and sustainable maritime ecosystem¹⁰¹. However, clean shipping's challenges, high costs, infrastructure gaps (e.g., 0.7% of ports offer hydrogen bunkering), and enforcement inconsistencies, must be addressed through global cooperation to realize its full potential¹⁰². For example: A green shipping operator retrofits a vessel with scrubbers for £3 million, achieving MARPOL compliance but facing future ETS costs and no measures for crime or inclusivity. A clean shipping operator invests £60 million in a hydrogen vessel, avoids ETS penalties, uses AI to prevent piracy, and ensures MLC-compliant gender equity, creating a sustainable, trusted maritime model.

8. Recommendations

To bridge the gap between green shipping's accessibility and clean shipping's ambitions, the following recommendations integrate practical and visionary strategies to advance a sustainable, ethical, and crime-free maritime future:

Hybrid Strategies: Combine green shipping's retrofitting with clean shipping's ethical and technological innovations. Operators can retrofit vessels with scrubbers or LNG systems (£2-5 million) as a transitional step while investing in clean shipping technologies like hydrogen propulsion and AI navigation over a 10-15-year horizon¹⁰³. For example, a hybrid approach could involve retrofitting a vessel with scrubbers to meet MARPOL Annex VI while piloting ammonia fuel trials, reducing emissions and preparing for net-zero goals¹⁰⁴. This balances cost-effectiveness with long-term sustainability, minimizing stranded asset risks¹⁰⁵.

Policy Incentives: Expand EU ETS subsidies for hydrogen and autonomous vessels. The EU ETS, which charges for carbon emissions, should increase subsidies for zero-emission technologies, covering 30-50% of hydrogen vessel costs (£50-100 million) to accelerate adoption¹⁰⁶. Incentives for autonomous vessels, like the Yara Birkeland, could reduce

¹⁰¹ DNV, *Maritime Forecast to 2050* (2023) <https://www.dnv.com/maritime/publications/maritime-forecast-to-2050-download>.

¹⁰² International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

¹⁰³ Lloyd's Register, *Cost Analysis of Scrubber Installation* (2023) <https://www.lr.org/en/insights/global-marine-trends/scrubber-costs>.

¹⁰⁴ Wärtsilä, *Ammonia as a Marine Fuel* (2023) <https://www.wartsila.com/marine/solutions/future-fuels/ammonia>.

¹⁰⁵ International Renewable Energy Agency, *Decarbonising Shipping: The Role of Hydrogen* (2023) <https://www.irena.org/Publications/2023/Dec/Decarbonising-shipping>.

¹⁰⁶ European Commission, *Fit for 55: EU Emissions Trading System* (2023) https://ec.europa.eu/clima/policies/ets_en.

implementation costs by £5-10 million per vessel, encouraging innovation¹⁰⁷. Such policies would align with the IMO's 2023 Revised GHG Strategy and drive economic sustainability through job creation in green technology¹⁰⁸.

Crime Minimization: Strengthen UNCLOS enforcement through international task forces equipped with AI and satellite monitoring to combat C3+ trafficking, smuggling, counterfeiting, war crimes, human rights violations, maritime zones violations, illegal surveys, and weapon-testing, targeting a 30% reduction in incidents.

Crime Minimization: Strengthen UNCLOS enforcement through international maritime task forces. UNCLOS (1982, Art. 99 and 101) mandates action against trafficking and piracy, but only 60% of coastal states actively enforce it¹⁰⁹. Establishing international task forces, equipped with AI surveillance and satellite monitoring, could reduce maritime crime by 30%, as seen in pilot projects¹¹⁰. For instance, a task force in the Gulf of Aden could use blockchain to track cargo, ensuring compliance with the UK Modern Slavery Act 2015 and reducing trafficking risks¹¹¹.

Inclusivity and Lifestyle: Mandate blockchain reporting to ensure transparency across all maritime crimes, enhancing stakeholder trust by 40%. Scale IMO's Women in Maritime programme and promote transparent reporting via blockchain. The Women in Maritime programme, which increased female technical roles by 3% since 2019, should be expanded with £50 million in funding to train 10,000 women seafarers by 2030, aligning with MLC (2006) protections¹¹². Blockchain-based reporting, as per the Poseidon Principles, should be mandated for operators, enhancing clarity and stakeholder trust by 40%¹¹³. For example, a clean shipping operator publishing blockchain-verified sustainability reports could attract ethical investors, reinforcing a transparent, inclusive maritime lifestyle¹¹⁴.

¹⁰⁷ Rolls-Royce, *AI and IoT in Maritime Operations* (2023) <https://www.rolls-royce.com/marine/solutions/digital>.

¹⁰⁸ International Maritime Organization, *2023 Revised IMO Strategy on Reduction of GHG Emissions from Ships* (2023) <https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx>.

¹⁰⁹ United Nations, *United Nations Convention on the Law of the Sea* (1982) https://www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf.

¹¹⁰ Global Fishing Watch, *AI in Maritime Surveillance* (2023) <https://globalfishingwatch.org/technology/ai-surveillance>.

¹¹¹ Modern Slavery Act 2015 (UK) <https://www.legislation.gov.uk/ukpga/2015/30/contents>.

¹¹² International Maritime Organization, *Women in Maritime Programme* (2023) <https://www.imo.org/en/OurWork/HumanElement/Pages/WomenInMaritime.aspx>.

¹¹³ Poseidon Principles, *Framework for Sustainable Ship Financing* (2019) <https://www.poseidonprinciples.org>.

¹¹⁴ A P Moller-Maersk, *Sustainability Report 2022* (2023) <https://www.maersk.com/sustainability/reports>.

For example: A hybrid strategy operator retrofits a vessel with scrubbers while piloting hydrogen, supported by EU ETS subsidies. An international task force uses AI to enforce UNCLOS, reducing piracy in key routes. Scaling the Women in Maritime programme trains 2,000 women annually, and blockchain reporting ensures clarity, creating a just, sustainable maritime ecosystem.
