A Holistic Approach for Sustainable Shipping

Mr. Praveen K. Mishra and Mr. Bhagatsingh P. Geda
Indian Register of Shipping
52A, AS Marg, Opposite Powai Lake, Mumbai - 400072, INDIA
Corresponding author's email: bhagatsingh.geda@irclass.org

Abstract - This paper examines the balance between efficiency and sustainability in maritime transport, advocating a holistic life cycle approach to ship design, construction, operation, and dismantling. With increasing global trade placing higher environmental demands on the shipping industry, innovative strategies are crucial to reduce emissions and enhance sustainability. Sustainability, encompassing economic, social, and environmental dimensions, is explored through Life Cycle Thinking. Integrating Life Cycle Assessments (LCAs), this approach guides design decisions to develop ships that are efficient, economically viable, and environmentally responsible throughout their lifecycle.

Keywords: Sustainability; UN SDG; IMO; Maritime Transport; Life Cycle Assessment; Ship Life Cycle

INTRODUCTION

In an environmentally conscious era, the maritime transport sector faces a complex balance between efficiency and sustainability. Despite being relatively energy-efficient and emitting fewer emissions per unit compared to other transport modes, the sector faces challenges as total emissions rise with global trade expansion. It is essential to align the entire supply chain with sustainable practices to ensure a cohesive strategy throughout the lifecycle of the ship. A holistic approach covering the entire lifecycle from design to dismantling is essential to address these concerns.

UNDERSTANDING "SUSTAINABILITY"

Sustainability, driven by its impact on environmental quality, economic development, and social equity, is crucial in transport initiatives. However, a universally accepted definition has remained elusive since the 1987 Brundtland Report, which defined sustainable development as meeting present needs without compromising future generations. [1].

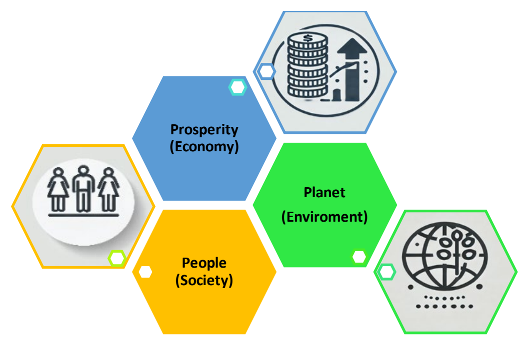

Figure 1 : Three Pillars of Sustainability

"Sustainability" and "sustainable development" are often used interchangeably, though they denote distinct concepts. Sustainability aims for a balanced state among economic, social, and environmental factors, considering indirect and long-term effects, while sustainable development is the ongoing process of achieving this equilibrium. Increasing consensus centers on the three pillars of sustainability—social, economic, and environmental—summarized as People, Planet, and Prosperity (PPP). Despite ongoing debates over their priorities, environmental concerns are frequently seen as fundamental for sustaining social and economic systems.

Figure 2: The United Nations Sustainable Development Goals (Source: Wikipedia)

UN & IMO Perspective on Sustainability & Sustainable Maritime Transport, respectively

In September 2015, the UN adopted 17 Sustainable Development Goals (SDGs) with 169 targets The SDGs are 17 time-bound, quantifiable objectives, and form the overarching global development framework from 2015 until 2030. In 2013, IMO adopted an official stance on sustainable maritime transport, outlined in the document "*A Concept of a Sustainable Maritime Transport System.*" This response highlighted the IMO's commitment to sustainability, defining a sustainable maritime system as one that *ensures safe, secure, efficient, and reliable transport of goods globally, while minimizing pollution, maximizing energy efficiency, and conserving resources.*[2]

IMO targets the UN's 2030 SDGs in its 2024-2029 strategic plan with eight strategic directions, focusing on implementing instruments, integrating technologies, addressing climate change, governance, trade facilitation, human elements, regulatory and organizational effectiveness. These efforts aim to advance sustainability and align with global goals.

LIFE CYCLE THINKING – A HOLISTIC APPROACH TOWARDS ATTAINING SUSTAINABILITY

The adoption of Life Cycle Thinking marks a significant shift from traditional environmental protection strategies to a more comprehensive view of sustainability. This approach assesses the entire life cycle of systems—such as ships—from resource extraction and raw material production, through transportation, assembly, and operation, to recycling and final waste disposal. By considering the full life cycle, this method helps prevent environmental impact shifts from one stage to another and identifies weak links in the environmental chain of the life cycle, ensuring that the sustainability of a system is genuinely holistic.

The Life Cycle Thinking approach is gaining traction with significant initiatives in Europe and globally. The European Platform of Life Cycle Assessment (EPLCA), managed by the EU's Joint Research Centre, enhances communication and data harmonization within the EU. Similarly, the UNEP/SETAC Life Cycle Initiative aims to standardize life cycle approaches worldwide.

The revised ISO 14001:2015 "Environmental Management Systems" emphasizes a Life Cycle Perspective, requiring assessment of environmental impacts across all stages—from design to disposal. It highlights transparency, control over outsourced processes, and specific environmental criteria in procurement and end-of-life treatment.

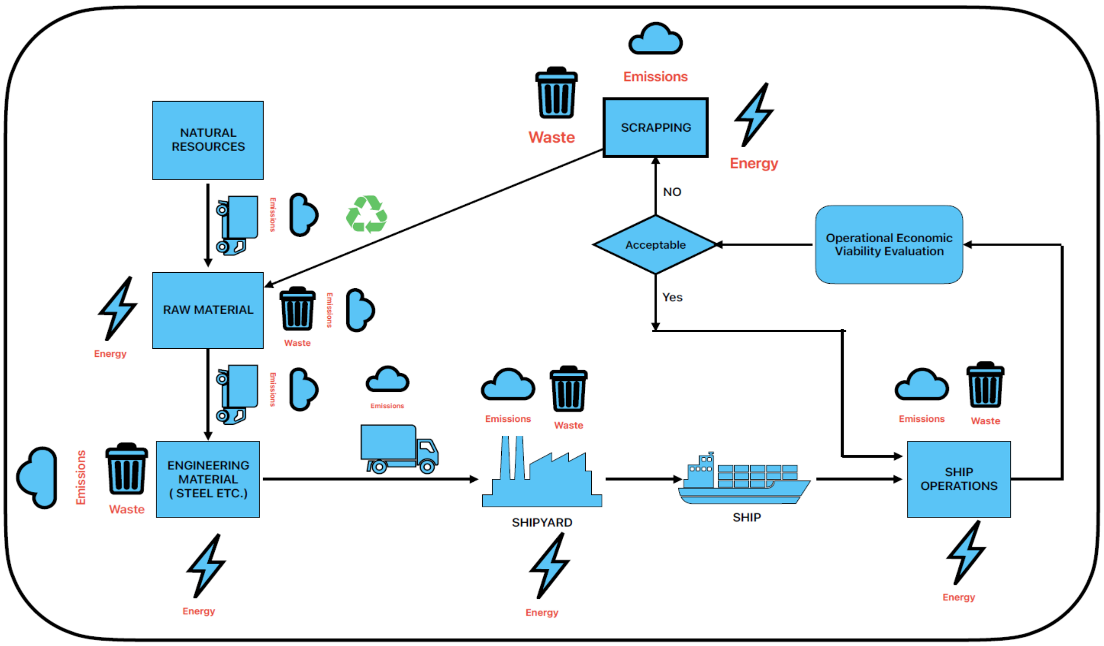

Figure 3: Energy demand and environmental impacts over the life cycle of a ship

LIFE CYCLE THINKING FOR AN ENVIRONMENTALLY SUSTAINABLE SHIP

Life cycle thinking should be integrated from the initial design stage, incorporating safety, economy, energy efficiency, environmental performance, and disposal. The design process should be holistic, fulfilling the following requirements:

- Compliance with IMO and other international conventions.
- Adherence to classification society requirements.
- Achievement of performance specifications.
- Rational use of materials.
- Reduction of energy consumption.
- Promotion of cleaner production methods.
- Minimization of environmental impacts.
- Reduction of solid waste production.
- Mitigation of challenges associated with ship demolition and waste disposal.

Figure 3 overviews the energy and resource demands and environmental impacts throughout a ship's life.

Ships' Life Cycle

A Ship's life cycle can be divided into the following (Refer Figure 4):

- *Upstream processes:* Extraction, processing and transport of the materials used for the vessel and manufacturing of its components.
- *Core process:* Vessel building and component installation up to the test/trials phase before delivery to the customer.
- *Downstream processes:* This phase maybe split into: Use phase, Maintenance Phase and End of Life Stage which comprises transport to the disposal site and disposal processes

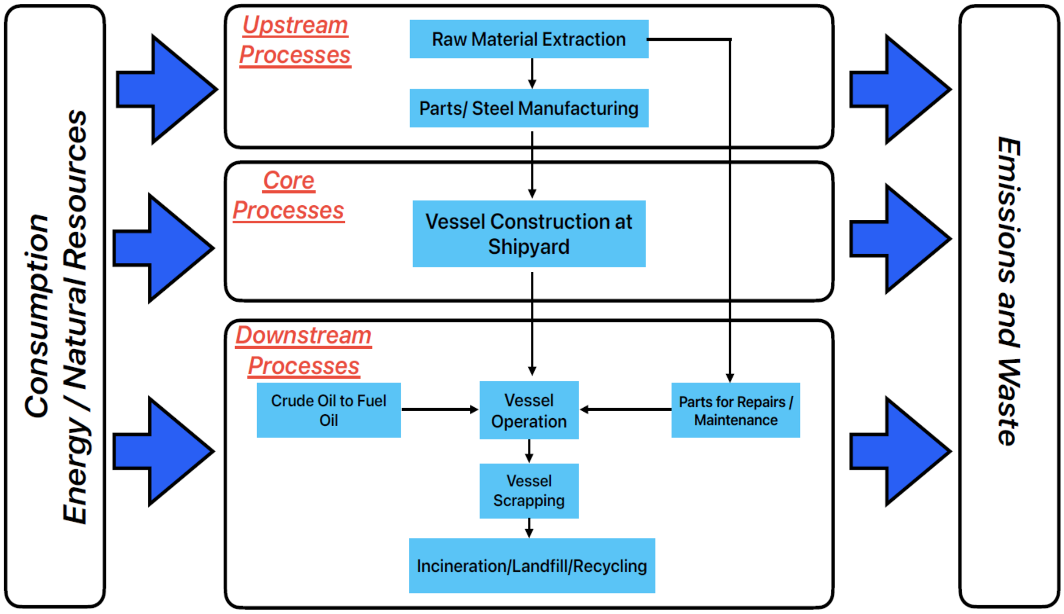

Figure 4: Ship's Lifecycle

Upstream Processes

Common shipbuilding materials, include steel plates and sections, welding coils and rods, castings, forged parts, timber, and paints. The selection of these materials should aim to reduce energy consumption and minimize environmental impacts while sustaining economic viability. Decarbonizing shipping extends beyond just changing fuels; as the focus on fuels intensifies, the importance of non-fuel related greenhouse gas (GHG) emissions increases. It is also crucial that vendors and suppliers align with these sustainability practices to ensure a consistent approach.

For Example, Steel is crucial in ship construction and central to decarbonization efforts, as the steel industry accounts for about 7% of global greenhouse gas emissions. To meet the 1.5°C climate target, a low-carbon process is essential. Recently, the concept of Green Steel has emerged, defined by SteelZero in 2022, which meets high ESG standards and reduces greenhouse gas emissions [6]

Producing shipbuilding-grade steel via a scrap-based Electric Arc Furnace (EAF) method is feasible. However, it is important to highlight that utilizing green hydrogen-based Direct Reduced Iron (DRI) EAF production could alleviate quality concerns, potentially facilitating the production of superior green steel for shipping. Nevertheless, this method faces challenges, primarily the dependency on high-quality iron ore, which is not universally available.[6]

Core Processes – Ship Construction

The construction phase offers significant opportunities for enhancing sustainability in shipbuilding. Adopting advanced manufacturing techniques like modular construction improves efficiency and leveraging digital engineering software and Industry 4.0 levers improves efficiency, lessens the environmental footprint compared to traditional methods. Efficient utilization of construction materials such as welding rods, paints, and energy during various fabrication processes (like cutting, forming, and welding) is crucial. Streamlining these processes, coupled with stringent quality control to minimize rework, can substantially lower energy consumption and emissions. At the design stage itself, energy efficiency can be improved by reducing the hull's steel weight, using alternative materials, and optimizing the weight and power requirements of engines and other components. During fabrication, energy efficiency gains are achieved through better inter-process transportation and material handling, advanced bending and forming techniques, and the use of larger steel plates. Enhancing welding operations and accuracy, reducing welding and cutting lengths, and employing computer-aided marking and cutting also contribute to efficiency. Efficient material usage and minimizing scrap and rework through improved plate nesting further support sustainability goals.

Downstream Processes

Downstream Process - Operation

The operational phase accounts for most of its environmental impact, primarily due to fuel consumption and the resulting emissions. Sustainable operation of ships can be achieved through practices such as slow steaming, which involves operating at lower speeds to reduce fuel use and emissions. Technological advancements like air lubrication systems, which reduce hull resistance, and the use of alternative fuels, such as LNG, hydrogen etc. can also make ship operations more sustainable.

Downstream Process - Maintenance

Maintenance practices significantly influence the sustainability of maritime operations. Regular maintenance ensures efficient operation and prolongs the lifespan of ships, which is crucial for reducing the need for frequent replacements. Moreover, using environmentally friendly paints and coatings can minimize the toxic substances that leach into marine environments.

End of Life

The end-of-life phase of a ship is as crucial for sustainability as other phases. Sustainable recycling should start at the design stage with selection and use of recyclable materials and ensure recycling yards meet strict environmental and safety standards. With the growing number of decommissioned ships, ship scrapping has become a significant industry. For ship owners, deciding whether to scrap, continue operations, or convert a ship involves thorough condition assessments and economic evaluations. Due to the high costs of acquiring new ships, owners may wish to extend their vessels' lifespans by upgrading the hull, machinery, or both, which conserves natural resources. Proper assessments of a ship's hull and machinery can guide owners in deciding whether to upgrade for continued operation or to scrap the vessel. The environmental and energy demands of ship scrapping include outputs such as reusable materials, repairable components, and recycled substances. Effective ship scrapping management can greatly enhances environmental performance by maximizing material reuse and minimizing waste and energy consumption, offering economic and environmental benefits.

SUSTAINABILITY ASSESSMENT

Effectively implementing sustainability remains a formidable challenge, particularly in measuring the sustainability performance of products and processes. This is crucial for determining whether initiatives genuinely contribute to sustainability goals. Life Cycle Thinking forms the foundation for assessing sustainability, requiring consideration of the entire life cycle of a product or process to evaluate all environmental aspects thoroughly.

Life Cycle Assessment

Life Cycle Assessment (LCA) is a scientific methodology designed to evaluate the potential environmental impacts associated with all the stages of a product's life—from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Defined by the ISO standard, LCA involves "*the compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle*" [3]. This holistic approach involves steps as described in Figure 5.

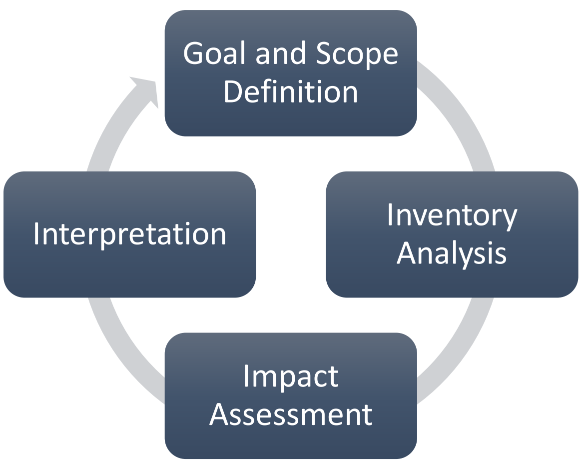

Figure 5: Steps in Life Cycle Assessment

Goal Definition and Scope: This initial phase defines and describes the product or process under review, setting the context and identifying the environmental aspects to be evaluated. It emphasizes defining a 'functional unit,' a quantifiable measure of system performance serving as a benchmark for all inputs and outputs. Additionally, it determines the system boundary, specifying included processes and impacts. System boundaries can vary depending on the scope of the LCA (Refer Figure 6). A Cradle-to-Grave assessment encompasses the entire product life cycle, from resource extraction to disposal. Cradle-to-Gate assessments cover the product life cycle up to the factory gate before the product reaches the consumer, while Gate-to-Gate assessments analyze a single production step within the broader production chain. Each approach provides a different perspective on environmental impact and sustainability.

Inventory Analysis: This step catalogues and quantifies the energy consumption, water, raw materials used, and environmental discharges (emissions, solid waste, wastewater) throughout the product life cycle. It focuses on detailed data collection to quantify system inputs and outputs.

Impact Assessment: This phase evaluates the environmental impacts of resource and energy use, as well as emissions identified in the inventory analysis. Results are displayed across indicators such as climate change potential, ozone depletion, human toxicity, resource depletion, eutrophication, energy demand, and greenhouse gas emissions (CO_2 equivalents).

Interpretation: This final phase interprets the data and impacts to identify the most environmentally preferable options, considering the uncertainties and assumptions used throughout the LCA.

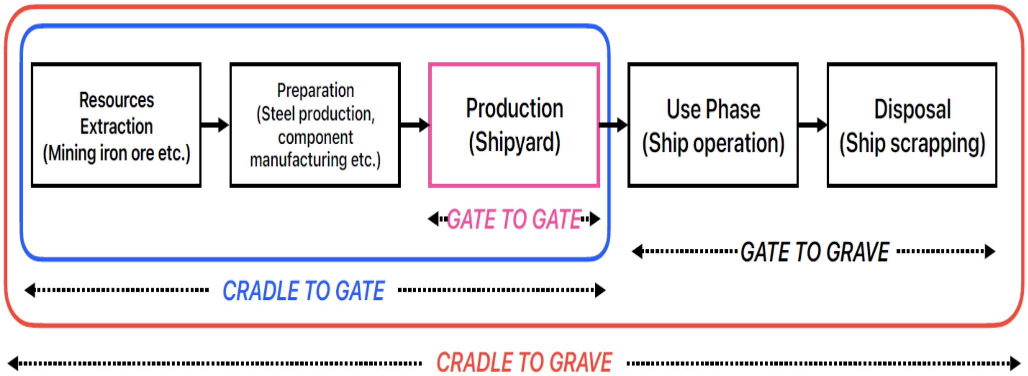

Figure 6: System Boundaries for Ship's Life Cycle

LCA studies adhere to the standards set by ISO 14040 [3] and ISO 14044 [4] ensuring a robust and reliable environmental assessment. LCA methodology not only facilitates the comparison of different materials and processes but also helps in identifying pollution transfers—often referred to as "burden shifting"—across different environmental impacts, life cycle stages, or systems. Consequently, LCA is invaluable in "design for the environment" strategies and supports informed decision-making in both business and policy contexts.

LCAs case studies for ships reveal significant impacts, particularly during the operational phase due to emissions like CO_2, NOx, and SOx, as shown by Kameyama et al. (2007).[11] This study highlighted key areas such as global warming and urban air pollution. A study by Barbara Busetto et al. (2022) emphasized the importance of assessing impacts from raw material extraction to end-of-life disposal through their study on a recyclable-material racing sailing boat.[12] These case studies underscore the need for standardized LCA approaches for fair comparisons and informed decision-making.

Life Cycle Assessment of a Ship – A template

An Environmental Product Declaration (EPD) is defined by ISO as a Type III declaration [5], quantifying environmental information across a product's life cycle to facilitate comparisons between products with the same function. EPDs, rooted in the LCA principles of the ISO 14040 series, support business interactions and aid environmentally conscious consumers in decision-making. These declarations help companies advance their sustainability goals and showcase their commitment to environmental stewardship.

While EPDs align with LCA methodology, variations in data and assumptions can cause inconsistencies in results for similar products. Product Category Rules (PCRs) address this by providing detailed guidelines that standardize comparisons within the same product category. PCRs define LCA goals, product categories, functional units, system boundaries, and other key parameters such as impact categories and data quality requirements. This structured approach ensures consistent and reliable environmental assessments across similar products.

PCR for "*Yachts, Small Crafts, Other Vessels, and Components Thereof*" within the international EPD system provides a robust LCA framework for ships/boats/vessels. It comprehensively covers all vital stages and processes in the life cycle of a vessel, offering an excellent starting point for organizations seeking to assess environmental performance.[7] By using this PCR, informed decisions about environmental impacts and implementation of effective sustainability strategies can be done.

BEYOND ENVIROMENTAL SUSTAINABLITY

Life cycle methods, akin to LCA, extend beyond environmental sustainability to address economic and social dimensions. Recent advancements aim to integrate these dimensions through LCA for environmental impacts, Life Cycle Costing (LCC) for economic considerations, and Social Life Cycle Assessment (SLCA) for social impacts.

Traditionally used for investment decisions, Life Cycle Costing (LCC) evaluates total discounted costs over a product's lifespan. The UNEP/SETAC Life Cycle Initiative advocates integrating sustainability into life cycle assessment methodologies, with SETAC's code of practice for environmental life-cycle costing (LCC) offering a structured approach to evaluating sustainability decisions [9].

SLCA is a developing methodology that faces challenges in quantifying subjective social impacts and achieving consensus on assessment categories to avoid oversimplification. SLCA aims to provide a comprehensive view of social impacts across a product's lifecycle, addressing the often less tangible social dimension of sustainability.[8]

Despite progress, further scientific development is needed to ensure consistency in life cycle sustainability frameworks, recognizing the complex interactions among environmental, economic, and social dimensions. Efforts are underway to develop sector-specific frameworks, such as for maritime transport, though these are still conceptual. Proposals exist for integrating techniques to analyze ships from a life cycle perspective, emphasizing separate assessments of the three sustainability pillars. [10].

CONCLUSION

Achieving sustainable maritime transport requires an integrated approach that considers every phase of a ship's life cycle, from design to disposal, with aligned supply chain practices. Embracing Life Cycle Thinking is a strategic decision that aligns with global sustainability goals and stakeholder demands for greener operations. This perspective embeds sustainability in all maritime decisions, particularly in design, construction, and operations, which greatly impact the environmental footprint of shipping. It necessitates a shift to innovative solutions, including sustainable materials, energy-efficient designs, and advanced technologies that enhance economic performance and social responsibility.

Life Cycle Assessments (LCAs) are crucial in this journey, providing a scientific basis to evaluate and mitigate environmental impacts. Alongside LCAs, Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA) offer comprehensive evaluations of economic and social impacts, respectively. These assessments enable informed decisions that support the longevity and sustainability of vessels. Achieving sustainable maritime transport requires cooperation among governments, industry stakeholders, and the global community to innovate, regulate, and adopt best practices for a sustainable and resilient future.

ACKNOWLEDGEMENT

The authors express their gratitude to the Indian Register of Shipping. The views expressed in this paper are solely of the authors and may not necessarily represent those of the Indian Register of Shipping.

References:

[1] Gro Harlem Brundtland, "*Our Common Future*" , Report of World Commission on Environment and Development, United Nations , 1987

[2] IMO Publication, A Concept of a Sustainable Maritime Transport, 2013

[3] ISO 14040, Environmental management – Life Cycle Assessment – Principles and framework

[4] ISO 14044, Environmental Management – Life Cycle Assessment – Requirements and Guidelines

[5]ISO 14025, Environmental labels and declarations — Type III environmental declarations — Principles and procedures

[6] *Green Steel and Shipping*, Sustainable Shipping Initiative, June 2023

[7] Product Category Rules for Yachts, Small Crafts, Other Vessels, and Components thereof, PCR 2015:06, International EPD System

[8] Guidelines for Social Lifecycle assessment of products, UNEP, 2009

[9] Swarr, Environmental life-cycle costing: a code of practice, 2011

[10] Oihane C. Basurko et. al. , *Methodology for the sustainability assessment of marine technologies*, 2011

[11] Kameyama et. al, *Study on Life Cycle Impact Assessment of Ships*, 2007

[12] Barbara Busetto et. al, *Life Cycle Assessment in the naval sector: between certification and new materials,* 2022

[13] Stefanos D. Chatzinikolaou, *Methodologies for assessing sustainability in maritime transport*, 2018

[14] Stefanos D. Chatzinikolaou et. al., *Assessing Environmental Impacts of Ships from a Life Cycle Perspective*. 2014