State-of-the-art sustainable energy efficiency technologies roadmap for waterborne transport towards the fit-for-55 guidance compliance

Project 101192661— FLEETfor55

Deliverable D2.1 – Review of Alternative Energy Efficiency Technologies (EETs) and Associated Techno-Economic Data

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Co-funded by the European Union

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Project 101192661 — FLEETfor55 — HORIZON-CL5-2024-D5-01

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Document Information

Document	
Title	State-of-the-art sustainable energy efficiency technologies roadmap for waterborne transport towards the fit-for-55 guidance compliance
Acronym	FLEETfor55
Call	HORIZON-CL5-2024-D5-01
Type of Action	HORIZON Innovation Actions
Grant Number	101192661
Start date	01-01-2025
Duration	42 months
Document identifier	D2.1 – Review of Alternative Energy Efficiency Technologies (EETs) and Associated Techno-Economic Data
Due Date of Delivery to EC	30-06-2025
Actual Date of Delivery to EC	30-06-2025
Dissemination level	PU – Public
Delivery Type	R – Report
Work package	WP2
Related Tasks	T2.2
Lead Beneficiary	7 – NTNU

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Reviewers (s)	2 - RINA 4 - NTUA

History Sheet			
Version	**Date**	**Editor**	**Summary of Modifications**
V0.1	19/05/2025	Dong Trong Nguyen (NTNU)	Document drafting
V0.2	17/06/2025	Johans Jacobo Jara (NTNU)	Document Pre-Submission Draft
V0.3	23/06/2025	NTUA | RINA	Document Reviewed Version
V1.0	30/06/2025	Johans Jacobo Jara(NTNU)	Final Submission Document

Acronyms and Abbreviations	Meaning
FLEETfor55	State-of-the-art sustainable Energy Efficiency Technologies roadmap for waterborne transport towards the fit-for-55 guidance compliance
GA	Grant Agreement / General Assembly (context-dependent)
AGA	Annotated (Model) Grant Agreement
CA	Consortium Agreement
CO	Project Coordinator
PMT	Project Management Team
WPL	Work Package Leader
WP	Work Package
TIN	Technologies Innovation Network
EAB	External Advisory Board
UC	Use Case
DMP	example
IPR	Intellectual Property Rights
LoI	Letter of Intent
CFS	Certificate on the Financial Statements
EC	European Commission
EU	European Union
MS Teams	Microsoft Teams
MoM	Minutes of Meeting
KoM	Kick-off Meeting
EETs	Energy Efficiency Technologies
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
SLCA	Social Life Cycle Assessment
HAZID	Hazard Identification

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Executive Summary

D2.1 delivers a comprehensive review and classification of Energy Efficiency Technologies (EETs), forming the foundation for techno-economic assessment across the fleet. The primary focus has been to identify relevant EETs, the number is the outcome of the investigation, map them across retrofit and newbuild contexts, and collect associated data on cost, energy performance, technical maturity (TRL), and operational relevance.

This review integrates a systematic literature methodology (PRISMA), expert consultation, and Technologies Innovation Network

(TIN) network feedback to ensure representativeness and technical validity. The categorisation framework allows the structuring of EETs by system-level application, optimisation focus, and specific technology, enhancing clarity in deployment and comparative evaluation.

A critical outcome is the harmonisation of techno-economic parameters, including capital and operational costs, energy savings, and lifecycle indicators necessary for the following feasibility and market analyses. The review also highlights the prioritisation of technologies with high industry engagement, such as Onshore Power Supply and Energy Management Systems.

Ultimately, D2.1 provides a structured, data-driven foundation for WP2, ensuring traceable, scalable, and industry-aligned evaluation of maritime EETs.

Chapter 1 Introduction

1.1 Background

The maritime transport sector is under increasing pressure to decarbonize, in alignment with international and European climate targets, particularly those set by the International Maritime Organization (IMO) and the European Union's Fit for 55 packages. More specifically, maritime transport accounts for approximately 13.5% of transport-related greenhouse gas emissions in the EU, with vessels above 5000 grosses tonnages (GT) , representing 55% of the fleet, contributing to nearly 90% of total maritime CO_2 emissions[1]. In this context, Energy Efficiency Technologies (EETs) represent a pathway for reducing greenhouse gas emissions, improving vessel performance, and ensuring long-term regulatory compliance.

The FLEETtFor55 project aims to provide a comprehensive roadmap for accelerating the deployment of EETs in the waterborne transport sector. The project focuses on identifying, benchmarking, and promoting the adoption of cost-effective technologies across various vessel types and operational profiles. Within this framework, Work Package 2 (WP2) plays a pivotal role by systematically identifying and evaluating available EETs and developing a knowledge base that supports decision-making across the entire project.

1.2 Objective and scope

The objective of this report is to search for and identify alternative EETs currently available or emerging for waterborne transport, i.e. in short sea, inland waterway, and high-seas transport. This activity forms part of Task 2.1 of the FLEETtFor55 project, which aims to support the EU's Fit for 55 climate objectives by facilitating the uptake of sustainable and efficient technologies in maritime operations.

Specifically, the work aims to:

- Identify and classify existing and emerging EETs relevant to the FLEETFor55 use cases.
- Evaluate both design and operational applicability of each technology.
- Collect and harmonize energy efficiency data.
- Distinguish technologies according to their applicability in newbuild versus retrofit scenarios.
- Provide structured input for subsequent tasks related to market analysis, feasibility evaluation, and the development of a decision-support system (T2.2–T2.5).

[1] European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions" - European Commission - Press release - Brussels, 14 July 2021 - "European Green Deal: Agreement reached on cutting maritime transport emissions by promoting sustainable fuels for shipping" - European Commission - Press release - Brussels, 23 March 2023

- Identify gaps or challenges exist in the available EETs, and how can stakeholder engagement (e.g., via the TIN) contribute to a more complete understanding of the EET landscape.

The scope of this work covers a spectrum of technologies that contribute to energy efficiency and emissions reduction. These include, but are not limited to:

- Power conversion and electrification systems
- Low-emission alternative fuels (e.g., hydrogen, ammonia, biofuels)
- HVAC systems and waste heat recovery
- Energy storage solutions
- Smart energy monitoring and management tools
- Renewable energy integration (e.g., wind-assisted propulsion)
- Hydrodynamic enhancements (e.g., hull coatings, air lubrication)
- Operational measures (e.g., slow steaming, just-in-time scheduling)
- Propulsion innovations (e.g., advanced propeller and rudder designs)
- Cold ironing and shore power connections

Technologies are assessed based on their technical maturity, economic viability, relevance to various vessel types and operating conditions. This evaluation is supported by experts and TIN which provide industry insights and validation. The resulting output is a structured EET catalogue and techno-economic database, serving as the foundation for benchmarking, market analysis, and decision-support activities in the next phase of WP2. A discussion on the methodology used for this assessment was included to justify the application of the PRISMA approach and ensure transparency and consistency in the selection process

Chapter 2 Methodology

2.1 PRISMA methodology

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines are designed to improve the rigor, transparency, and reproducibility of systematic literature reviews. Given the need for a comprehensive and methodical identification of alternative Energy Efficiency Technologies (EETs), applying PRISMA ensures a structured screening process, clear documentation of inclusion and exclusion criteria, and transparency in data sources, selection methods, and underlying rationale. The data gathering process involved systematic searches across multiple databases and repositories, ensuring a broad and representative collection of relevant studies and reports.

This aligns well with the goal of creating a techno-economic EET database that is credible, defensible, and robust for decision-making under WP2.

Based on the goal of the literature review, the literature review systematically searches multiple sources:

- Scientific databases: Scopus, Web of Science, ScienceDirect.
- Technical reports: IMO, EMSA, DNV, EU Fit for 55 documents.
- Industry white papers and TIN/EAB partner input.

Keyword-Driven Literature Search Methodology

A multi-stage filtering process was applied (see Figure. 1), starting with broad database queries on energy efficiency technologies, narrowed to maritime relevance using specific terms. After duplicate removal and abstract screening, 71 unique references remained. Full texts were assessed for relevance, quality, and publication criteria. Studies were then categorized by fuel type, methodology, and perspective to form a validated evidence base for the systematic review and techno-economic analysis.

Application of Keyword-Based Search Strings

Search Parameters

- Time Range: Last 10 years (2014–2024)
- Document Types: Article, Review, Book Chapter, Book, Data Paper, Article in Press, Journal
- Language: All

Database Search Results

Scopus:

- Initial search ("Energy efficiency technology"): 130,746 results
- Refined search ("Energy efficiency technology AND maritime OR shipping"): 790 results
- Targeted search string:
  TS = (("energy efficiency technology*" OR "fuel saving" OR "retrofitting") AND ("maritime" OR "shipping")) : 57 results

ScienceDirect:

- Initial search ("Energy efficiency technology"): 235,335 results
- Refined search ("Energy efficiency technology AND maritime OR shipping"): 33,803 results
- Targeted search string:
  TS = (("energy efficiency technology*" OR "fuel saving" OR "retrofitting") AND ("maritime" OR "shipping")) : 6,489 results

Eligibility Assessment of the Unique References

1. Identification

- Objective: To gather a comprehensive pool of sources related to Energy Efficiency Technology, alternative marine fuels and decarbonization strategies.

- Action Taken:

  - Searched multiple databases, repositories (e.g., ScienceDirect, Google Scholar, ResearchGate), and regulatory/classification parties (e.g., IMO, Lloyd's Register).
  - Included grey literature: industry reports, policy briefs, and technical documentation.

- **Total Records Identified**: Approx. 85 citations (including duplicates).

2. Screening

- Objective: Remove irrelevant or duplicate sources.

- Action Taken:

  - Screened titles and abstracts for relevance to marine fuels, emissions, techno-economic evaluation, and future fuel pathways.
  - Removed 14 duplicate entries (as shown in the previous summary table).

- **Records After Screening**: 71 unique references.

3. Eligibility

- Objective: Assess full texts for quality and relevance.
- Inclusion Criteria:
  - Studies published within the last 10 years (2014–2024).
  - Peer-reviewed articles, official reports, and conference proceedings. Coverage of alternative marine fuels such as methanol, ammonia, hydrogen, LNG, biofuels, and synthetic fuels.
  - Life Cycle Assessment (LCA), Techno-Economic Analysis (TEA), or environmental impact assessment.
- Exclusion Criteria:
  - Studies focused solely on non-maritime sectors.
  - Reports lacking quantitative data or peer-review validation.
  - Duplicated publications from the same authors with overlapping content.
- **Result**: Retained 71 sources that met all criteria.

4. Inclusion

- Objective: Final selection for in-depth analysis.
- Action Taken:
  - Categorized the 71 studies by fuel type (e.g., methanol, hydrogen), methodology (LCA, TEA), and perspective (academic, industry, TIN network).
  - Used for: Comparative analysis of fuels (performance, cost, emissions), Trend identification in fuel adoption and policy, Data extraction for modelling and scenario building.
- **Outcome**: These 71 references formed the core dataset for the systematic review, forming the evidence base of the research.

Summary of the PRISMA Screening and Eligibility Process

Overview of the systematic review process following PRISMA guidelines. The four stages: Identification, Screening, Eligibility, and Inclusion, are detailed with the specific actions taken at each step and the corresponding results obtained throughout the review.

Table 1.Overview of the systematic review process following PRISMA guidelines.

Stage	Purpose	Actions Taken	Application
1. Identification	To locate all relevant studies from databases and other sources	Conducted broad search in academic databases (e.g., Google Scholar, Scopus) and grey literature sources	**85** total records initially identified
2. Screening	To remove duplicates and clearly irrelevant studies	Titles and abstracts reviewed; duplicates removed	**14** duplicates excluded, resulting in 71 unique references
3. Eligibility	To assess full-text articles for relevance and quality	Applied inclusion/exclusion criteria: focus on marine fuels, LCA, TEA, decarbonization, etc.	All **71** studies reviewed in full and determined eligible
4. Inclusion	To include the final set of studies for qualitative or quantitative analysis	Studies included in synthesis and analysis, often categorized by fuel type, method, or focus area	All **71** references formed the core evidence base for the systematic review

PRISMA Flow Diagram

Identification
  ├– Records identified through database searching: 85
Screening
  ├– Records after duplicates removed: 71
  ├– Records screened by title/abstract: 71
Eligibility
  ├– Full-text articles assessed: 71
  ├– Articles excluded: 0 (based on defined criteria)
Included
  └– Studies included in final analysis: 71

The references presented in Appendix A on page 6311 are derived from a comprehensive and structured evaluation of literature, employing a systematic review methodology. The process incorporated four distinct source categories to ensure breadth and relevance:

1. Systematic Review of Literature Sourced from the EET Techno-economic reference
2. Systematic Review of Literature Sourced from the EET vs. Segment Matrix Database,
3. Systematic Review of Literature Sourced from WP2.1 (Responsible Partner NTNU) – Peer-Reviewed Journal Articles
4. Systematic Review of Literature Sourced from WP2.1 (Responsible Partner NTNU) – Reports and Publications.

An initial total of 85 references were identified across these databases and repositories. Following a rigorous screening process, 71 references were deemed eligible and included for evaluation. The discrepancy between the total identified and included sources is attributed to 14 repeated references, which were removed to ensure analytical accuracy. Consequently, the final dataset consists of 71 unique references.

This reference pool forms the evidential basis for the evaluations presented in this report and ensures that the included materials are representative, non-redundant, and of high academic and technical integrity.

Figure 1 presents the flow diagram of the PRISMA methodology, illustrating the systematic process of meta-analysis applied in this study. It details the sequential stages of identification, screening, eligibility assessment, and final inclusion of studies and reports. The diagram captures the integration of both previous and new studies and reports, showing how sources were filtered through each phase. The process ultimately resulted in the inclusion of 71 studies, comprising a combination of detailed reports and literature reviews, forming the evidence base for this research.

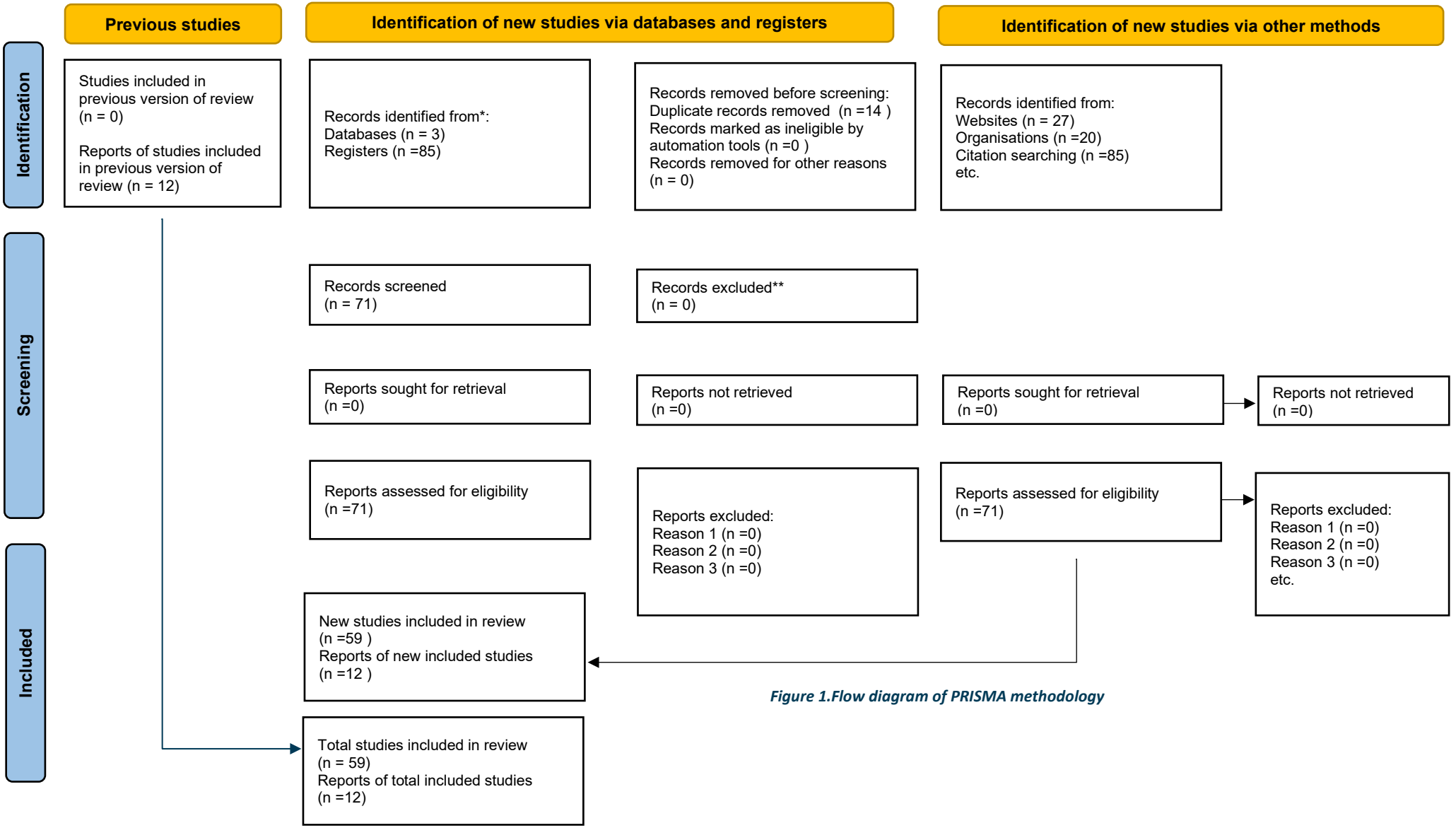

Figure 1.Flow diagram of PRISMA methodology

2.2 Data collection

1. Diagnostic Phase – Preliminary Data Assessment

The initial step involved a diagnostic mapping exercise aimed at identifying, cataloguing, and understanding the scope and nature of existing data across the project landscape. This baseline assessment enabled Task 2.1 to recognize existing data silos, gaps, overlaps, and potential alignment opportunities within the broader FLEETfor55 initiative.

2. Strategic Planning – Adoption of PRISMA Methodology

Following the diagnostic phase, a strategic plan was developed to systematically guide the data gathering process. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology was adopted as the core framework. This methodology ensured transparency, replicability, and methodological robustness in the literature and data review processes.

3. Data Capture and Structuring

The data capture phase was executed in three key sub-processes from all stakeholders:

3.1 General Analysis of Available Data

A comprehensive survey and assessment were conducted on all existing data contributed by Beneficiaries (BENs), Affiliated Entities (AEs), and Associated Partners (APs) under EU regulations. This step aimed to collect the full scope of potentially relevant data across institutions.

3.2 Data Simplification

Under the responsibility of Task 2.1, a data simplification process was implemented. This involved the elimination of redundancies, identification of duplicate entries, and streamlining of overlapping datasets to increase coherence and analytical efficiency.

3.3 Data Harmonization

The harmonization process ensured semantic and structural alignment across domains. It involved the standardization of terminology, categorization, and metadata structuring across all participating BENs, AEs, and APs, thus creating a unified data foundation ready for analytical use.

4. Post-Harmonization Validation of EET Data

Once harmonized, the EET (Energy-Efficiency Technologies) data underwent a dual-layered validation process:

4.1 Internal Validation

Conducted by Task 2.1 responsible partner (NTNU), this step verified the internal consistency, completeness, and technical accuracy of the harmonized data.

4.2 External Validation

Consortium partners and associated organizations participated in an external review process to ensure that the validated data reflected real-world conditions, sectoral expertise, and cross-organizational perspectives.

FLEETfor55-Multidimensional Insight Framework: Criteria Matrix for Source Evaluation

Throughout the entire data collection and validation pipeline, all inputs were evaluated against the Multidimensional Insight Framework: Source Criteria Matrix developed under Task 2.1. The FLEETfor55 project employs a **Criteria Matrix** to systematically assess the quality, relevance, and credibility of all data inputs across three source categories within the Task 2.1:

1. **Literature Review** – Peer-reviewed articles, reports, and policy documents.
2. **Experts & Consultants** – Technical advisory input from domain specialists.
3. **Technological and Innovation Network** – Stakeholder-driven insights aligned with EU maritime decarbonization goals.

Key Functions of the Matrix

- Quality Assurance: Validates sources against predefined rigor, transparency, and inclusivity standards.
- Strategic Relevance: Aligns evidence with interdisciplinary Energy efficiency technologies challenges within the maritime industry (policy, technology, operations).
- Holistic Integration: Combines academic, industry, and stakeholder perspectives to build a robust knowledge base.

Framework for Evaluating Sources Across Multiple Dimensions

Table 2: Summary of the multidimensional source evaluation criteria used in the assessment of Energy Efficiency Technologies (EET). The table categorizes the criteria into three main types of sources: literature review, experts and consultants, and the TIN network. Each column outlines the specific criteria applied and provides clear definitions for each, illustrating how these criteria were integrated into the evaluation process within the EET assessment matrix to ensure a comprehensive and balanced analysis.

Table 2.Summary of multidimensional source evaluation criteria.

Source Type	Criteria	Definition
1. Literature Review	Relevance	The degree to which the literature directly addresses the goals, technologies, policy scope, or sustainability dimensions of FLEETfor55.
	Credibility	The trustworthiness of the source, typically from peer-reviewed journals, academic publishers, or authoritative policy documents.
	Date of Publication	Preference for recent publications (last 5 years) to ensure up-to-date insights, especially for tech, policy, and regulatory developments.
	Methodological Rigor	The clarity, transparency, and reliability of the research methods used in the source.
	Geographic Applicability	The extent to which findings are relevant to the EU context, especially maritime and transport policy within EU Member States.
2. Experts & Consultants	Type of Involvement	Role and function (advisory, implementation, evaluation) in the project or action.
	Institutional Affiliation	Whether the expert or consultant is a Beneficiary (BEN), Affiliated Entity (AE), or Associated Partner (AP) under the EU regulation.
	Experience/Track Record	The individual's or institution's background in maritime transport, climate policy, or related sustainability domains.
	Independence/Conflict of Interest	Extent to which the expert provides objective input, without conflicting business or policy interests.
	Contribution Type	Nature of contribution: knowledge transfer, strategic advice, technical design, etc.
3. TIN Network	Node Expertise	The specific domain expertise provided by each TIN (Technology Innovation Network) node
	Representativeness	Extent to which the node represents relevant stakeholders (industry, academia, public sector).
	Connectivity/Dissemination Potential	Ability of the node to relay and disseminate findings across national and EU-level networks.
	Data Sharing/Collaboration	Willingness and capacity to provide relevant datasets or engage in cross-project collaboration.
	Strategic Alignment	How well the node's agenda aligns with the FLEETfor55 objectives, especially regarding decarbonization and innovation in maritime transport.

2.3 Matrix Methodology Justification for Technology Applicability, Feasibility, and TRL

A matrix that evaluates energy efficiency technologies across key dimensions: applicability, feasibility, and TRL, tailored to newbuilds and retrofits, and specific maritime segments (Inland Waterway Transport, Short Sea Shipping, Oceangoing), is a necessary tool. The maritime industry is highly diverse in operational needs, regulatory pressures, design constraints, and economic realities. A matrix approach captures this variability by providing a comparative, evidence-based structure that helps stakeholders understand how each EET performs in different settings, enabling more targeted and impactful implementation.

The matrix supports practical decision-making by addressing key factors:

- Sector-specific suitability (IWT, SSS, OG)
- Technology maturity (e.g., TRL 5 vs. TRL 9)
- Feasibility for newbuild vs. retrofit
- Nuanced applicability scoring
- Policy and funding alignment
- Fleet modernization and ESG strategy support

Assessment of Applicability, Feasibility, and TRL Metrics

Table 3. Terms of evaluation for Energy Efficiency Technologies (EETs), with detailed explanations for each criterion used in the assessment process. Applicability [a] assesses how suitable a technology is within various maritime sectors and operational conditions. Feasibility [b] considers practical implementation aspects, including technical integration, cost, and compatibility with newbuilds or retrofits. TRL [c], scored from 1 to 9, reflects the technology's maturity, from initial concept to full commercial deployment.

Table 3. Terms of evaluation of Energy Efficiency Technologies (EETs).

Matrix Terms	
Term	Explanation
Applicability [a]	Reflects the suitability of EETs for each vessel segment, considering its design, operation and regulatory context.
Feasibility [b]	Reflects how practical the implementation of each EET is for each vessel segment, considering cost, maintenance, crew training and integration with existing systems.
Technological Readiness Level (TRL) [c]	Critical for assessing innovation maturity, guiding funding decisions, and reducing deployment risks. They provide a standardized framework to evaluate technical feasibility and commercialization potential across industries.

Evaluation Scale for Term Matrix Outcomes

Table 4: Matrix rating scale for evaluating Energy Efficiency Technologies (EET) with detailed explanations of the applicability and feasibility ratings. Applicability is rated High [x] when technologies align well with operational and regulatory contexts; Moderate [y] when adjustments are needed; Low [z] when unsuitable. Feasibility is High if deployment is straightforward with low barriers; Moderate when challenges exist; and Low if significant technical, financial, or infrastructural obstacles prevent implementation. This scale supports informed, context-sensitive evaluations.

Table 4.Matrix rating scale for Energy Efficiency Technology (EET) derived from the multidimensional source evaluation criteria.

	Term Matrix Results Scale		
Term	High [x]	Moderate [y]	Low [z]
Applicability	The EET is widely suitable for vessel segment. It aligns well with operations, ship design and regulatory needs.	Suitable under specific conditions: vessel type and routes.	EET doesn't fit the vessel's type environment, design, or operations
Feasibility	EET is practical and realistic to implement. Installation, operation, maintenance and costs are manageable.	Can be implemented, facing some challenges (e.g. high cost, space needs, complexity)	Impractical implementation due to financial and technical barriers

Applicability vs. Feasibility Example: Onboard Carbon Capture Systems (CCS) are considered applicable for Inland Waterway Transport (IWT) vessels because these vessels emit CO_2 and often operate in Emission Control Areas (ECAs), where stricter environmental regulations apply. However, the feasibility of implementing CCS in IWT is moderate due to several constraints. These include limited onboard space, weight sensitivity, and budget limitations typically associated with IWT operations. CCS systems are inherently heavy and expensive, requiring substantial modifications that may only be practical in newbuilds or major retrofits. Moreover, the storage, handling and disposal of captured CO_2 onboard presents significant logistical and safety challenges, further reducing the practical viability of this technology in the short term.

Chapter 3 Boundary conditions for fleets

The implementation of EETs within the maritime and inland transport sectors requires the application of well-defined boundary conditions. These conditions are crucial to ensuring that the assessment, selection, and deployment of EETs are grounded in technical feasibility, regulatory compliance, and operational relevance. In the FleetFor55 project, boundary conditions are established based on both legal frameworks and practical constraints at the vessel and fleet levels, considering the varying profiles of transport modes and vessel categories.

3.1 Legal and Operational Framework for EET Evaluation in FLEETFor55

As outlined in the Grant Agreement, the identification and applicability of EETs are constrained by the legal and operational definitions assigned to key transport modes. These definitions shape the scope of Work Package 2. (WP2)**,** which focuses on fleets under EU law. The project evaluates EETs against these transport modes and vessel categories:

1. IWT (Inland Waterway Transport)

- Definition: Transport of goods or passengers via navigable rivers, canals, and lakes within EU territory using inland vessels.
- Legal Context: Governed by EU regulations such as Directive (EU) 2016/1629 (technical requirements for IWT) and aligned with the EU Green Deal and Smart Mobility Strategy .

2. SSS (Short Sea Shipping)

- Definition: Maritime transport of cargo and passengers between ports in the EU or nearby non-EU countries without crossing an ocean.
- Legal Context: Recognized under TEN-T Regulation (EU) 2021/1153 as a sustainable alternative to road transport and prioritized for modal shift to reduce emissions.

3. OG (Oceangoing)

- Definition: Residual category including vessels or transport operations not classified under IWT or SSS, such as: Fishing vessels, Offshore service vessels (OSVs), Research ships and Military and law enforcement fleets (where applicable).
- Legal Context: These may fall under Directive (EU) 2009/45/EC (safety rules for passenger ships) or other sector-specific frameworks and are considered in Fleetfor55 where relevant to innovation or decarbonisation goals.

3.2 Boundary Conditions for EET Applicability

The identification of Energy Efficiency Technologies (EETs) originated from the pre-identified categories and the number of EETs outlined in the Grant Agreement, detailed specifically in Step 2 (Part B, page 10 of 34). The evaluation of the total number of EETs is ongoing; as of this report, 67 technologies were accounted for following the Trondheim GA meeting. However, this report considers 68 EETs, as reflected in the analysis with the matrix updated just before this latest change. Despite this numerical update, the original categories remain unchanged.

Not all 70+ EETs identified in FLEETFor55 are universally applicable across all vessel types and operational contexts. Several boundary conditions affect their feasibility and strategic value. These are grouped into two primary analytical perspectives:

3.2.1. Vessel-Level Analysis (Ship-Specific)

- Definition: Vessel-level analysis focuses on the individual ship as the unit of compliance and optimization under the legal framework.

In FuelEU Maritime Regulation[2]

- Each ship over 5,000 GT is legally required to monitor, report, and reduce its greenhouse gas (GHG) intensity of energy used onboard.
- The target GHG reduction trajectory begins at 2% in 2025, increasing incrementally to 80% by 2050.
- Each vessel must demonstrate annual compliance with this decreasing GHG intensity benchmark.
- The analysis includes assessing the technical suitability of EETs, fuel choices, and operational changes tailored to each vessel's type (e.g., inland, coastal, deep-sea).

- Key Applications in FLEETFor55

  - Case-by-case use-cases (e.g., retrofitting a tugboat vs. a container ship).
  - Evaluation of how 70+ identified EETs apply differently depending on the vessel's operational profile and technical constraints.

[2] European Commission. (2023). Decarbonising maritime transport – FuelEU *Maritime*. Retrieved from https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime_en

3.2.2. Fleet-Level Analysis (Group Compliance)

- Definition: Fleet-level analysis considers a group of vessels operated by the same company or under a shared compliance agreement. The focus is on aggregated performance and strategic management across the fleet.

In FuelEU Maritime Regulation [3]

- Ships are permitted to pool their GHG performance via compliance pooling, a legally recognized mechanism.
- Operators can offset non-compliance of one vessel with the overperformance of another within the same pool.
- Pooling must be pre-agreed and declared, and vessels in a pool cannot use the borrowing mechanism for compliance deficits.
- This mechanism enables cost optimization and flexibility in investment and retrofitting decisions across a mixed fleet.

- Key Applications in FLEETFor55

- Scenario analysis for fleet-wide strategies.
- Identifying synergies between ships, where higher-performing vessels can help offset compliance burdens for others. This will be even more relevant with the introduction of the IMO Net-zero Framework, This will be the first in the world to combine mandatory emissions limits and GHG pricing across an entire industry sector and is set to be formally adopted in October 2025 before entry into force in 2027, to become mandatory for large ocean-going ships over 5,000 GT, which emit 85% of the total CO_2 emissions from international shipping.
- Development of aggregated techno-economic models for investment in EETs across fleets.

Framework for Level-Based Analysis

Table 5 provides a comprehensive summary of the analytical perspectives used in the assessment of Energy Efficiency Technologies, contrasting vessel-level and fleet-level approaches. The table outlines key aspects including the unit of analysis, legal and regulatory frameworks applicable to each level, methods of compliance monitoring, optimization strategies employed, and how these perspectives are applied within the FLEETfor55 project. This comparison highlights the strengths and limitations of each scale, supporting a holistic evaluation of technology impacts across operational contexts.

[3] Clyde & Co. (2024). FuelEU Maritime Series – Part 4: Compliance and Adjustment Mechanisms. Retrieved from https://www.clydeco.com/en/insights/2024/12/fueleu-maritime-series-part-4-compliance-and-adjus

Table 5. Analytical perspective summary: Vessel Level vs Fleet Level assessment.

Aspect	Vessel-Level Analysis	Fleet-Level Analysis
Unit of analysis	Single vessel	Multiple vessels (fleet/pool)
Legal basis	FuelEU Maritime Regulation, Article 4–6	FuelEU Maritime Regulation, Article 7 (Pooling)
Compliance responsibility	Individual vessel owner/operator	Operator or pool coordinator
Optimization scope	Technical & operational solutions per vessel	Strategic deployment of EETs across multiple vessels
Application in FLEETFor55	Use-case studies (newbuild & retrofit)	System-level modelling and optimization scenarios

3.2.3. Thematic Clustering (categorization)of EETs by Functionality and Integration Domain

To streamline analysis and ensure relevance, EETs are categorized into seven thematic clusters:

1. **Hydrodynamics Efficiency Improvements**.
2. **Propeller and Propulsion Optimization**.
3. **Operations and Digital Optimization**.
4. **Sustainable, Climate-Neutral and Low-Emission Fuels.**
5. **Power Conversion, Electrification, and Energy Devices.**
6. **Optimized Engineering Approaches**.
7. **Renewable Energy Integration**.

Boundary Condition Justification:

- Not every vessel has the space, operational profile, or route predictability to accommodate certain clusters.
- Example: Deep-sea vessels may benefit from alternative fuels, while inland vessels are more suited for electrification and energy management solutions.

3.3 Importance of EET Classification by Sector

The classification of EETs according to transport mode and vessel type is central to the FLEETFor55 analytical approach. This classification enables:

- Targeted applicability assessment, considering operational limits and regulatory compliance.
- Feasibility evaluation of retrofit versus new-build integration for each EET.
- Sectoral alignment with EU decarbonisation goals, especially under the FuelEU Maritime framework and Green Deal targets.
- Optimized investment and implementation strategies at the fleet level, accounting for inter-vessel synergies and pooled compliance potential.

Chapter 4 Classification of EETs

A transparent and inclusive classification of EETs was developed as a foundational step in the FLEETFor55 project. This process ensured that technological pathways toward fleet decarbonisation reflect the diversity of industrial innovation, stakeholder input, and regulatory feasibility. The categorisation process involved multiple stages of engagement with companies across the maritime value chain, ensuring broad representativeness and technical robustness.

4.1 Categorisation Process of EETs

The EET categorisation process was conducted in three iterations, designed to sequentially map the technologies represented by different industry stakeholders, starting from confirmed TIN members to potential contributors.

- First Iteration: Confirmed TIN Members: Involved 16 companies confirmed as part of the TIN, represented 10 distinct technology categories. This stage enabled initial validation of core EET families and identification of implementation-ready solutions.

- Second Iteration: Additional Technology Contributors: Included 6 companies not originally in the confirmed TIN but active in key areas of fleet innovation, represented 4 additional technology categories. This phase expanded the technological landscape and ensured the inclusion of emerging innovations.

- Third Iteration: Foreseen TIN Members: Mapped 105 companies across Europe that were not yet part of the network but demonstrated relevance to FLEETFor55 goals, represented a comprehensive set of 37 EET-related technology areas.

Across these three iterations, a consolidated list of 68 EETs was developed. These technologies were grouped into 7 provisional sector categories, aligned with the technical domains used in the TIN-TBD categorisation framework. This iterative and participatory approach ensured sectoral coverage and representation of both mature and developing technologies.

4.2 Matching Companies with the EET List

Following the categorisation, a detailed mapping was conducted to match companies to the 68 identified EETs. This mapping distinguishes between:

- 127 companies identified as EET technology providers, and
- 23 partners that are part of the FLEETFor55 consortium, including industrial, research, and policy institutions.

The EET-company matching process revealed specific demand patterns across the maritime technology ecosystem. The Top 5 most frequently matched EETs, indicating the highest interest and perceived applicability by companies, were:

1. Onshore Power Supply (OPS): Expressed interest by 15 companies.
   Critical for port electrification and shore-based emissions reduction.

2. Energy Management Systems (EMS): 11 companies.
   Central to optimizing vessel energy consumption and enabling digital control of energy flows.

3. Onboard Power Systems and Power Electronics: 11 companies.
   Includes converters, solid-state transformers, and advanced switching technologies to enable hybrid or electric propulsion.

4. Hydrogen Technologies: 9 companies. Encompasses fuel cells and hydrogen combustion systems, often aligned with long-term zero-emission pathways.

5. Energy Storage Systems (ESS) – Lithium-Ion Batteries – 9 companies.
   A key enabler of hybridization, electrification, and peak load smoothing.

This matching process illustrates both technological maturity and market pull, forming the basis for the techno-economic analysis and pilot selection in subsequent work packages.

4.3 Thematic Clusters(categorization) of EETs

To facilitate systemic analysis, the 68 EETs were organised into seven thematic clusters, based on their functional domain and integration logic. The clustering also reflects the maturity and diffusion of technologies across the sector.

The number of EETs per category is as follows:

1. Power Conversion, Electrification, and Energy Devices: 17 EETs
   Includes onboard power electronics, electric propulsion systems, and energy management components.

2. Sustainable, Climate-Neutral, and Low-Emission Fuels: 9 EETs
   Covers technologies supporting the use of hydrogen, methanol, ammonia, biofuels, and LNG.

3. Propeller and Propulsion Optimisation: 9 EETs
   Includes advanced propellers, azimuth thrusters, and propulsion control systems.

4. Operations and Digital Optimisation: 9 EETs
   Encompasses voyage planning tools, AI for fuel efficiency, and condition-based maintenance systems.
5. Renewable Energy Integration: 8 EETs
   Includes wind-assisted propulsion, onboard solar PV systems, and rotor sails.

6. Optimised Engineering Approaches: 8 EETs
   Encompasses modular construction, lightweight materials, and thermal insulation.

7. Hydrodynamic Efficiency Improvements: 7 EETs
   Covers air lubrication systems, hull shape optimisation, and antifouling coatings.

4.4 Final List and Classification Summary

The comprehensive classification of EETs, combining company engagement, functional categorisation, and matching with market needs, has produced a robust framework for further analysis in the FLEETFor55 project.

The final dataset includes:

- 68 Energy Efficiency Technologies (EETs)
- 7 Thematic Categories
- 127 Companies identified as EET providers
- 23 Consortium Partners contributing to knowledge, validation, and policy alignment

The complete classification of EETs per category, along with detailed descriptions, is provided in Appendix B. This classification serves as a foundational reference for identifying technology readiness, matching EETs to vessel types, and developing investment strategies under fleet-level decarbonisation pathways.

Three (3) main vessel segments:

1. Inland Waterway Transport (IWT)
- Vessels operating on rivers and canals.
- Typically have stricter constraints on size, draft, and emissions.
- Shorter routes and proximity to infrastructure favor electrification and operational efficiency improvements.

2. Short Sea Shipping (SSS)
- Coastal and regional sea routes, usually within the same continent (e.g., Europe).
- Moderate voyage distances; flexibility for using alternative fuels and hybrid technologies.
- Ideal segment for technologies like wind-assisted propulsion and advanced voyage planning tools.

3. OG – Ocean-Going Vessels (OG)
- Long-haul intercontinental vessels (e.g., tankers, bulk carriers, container ships).
- Highest energy demand and emissions footprint.
- Suitable for large-scale fuel technologies (e.g., ammonia, LNG, CCS), advanced hydrodynamics, and propulsion optimization.

Categorized Results of EET Matrix Following Application of Multidimensional Evaluation Criteria

Following the application of the evaluation criteria to each EET, based on the multidimensional framework established during the data collection phase, including applicability, feasibility, and TRL, a comprehensive assessment was conducted. This assessment was grounded in the regulatory context for both newbuilds and retrofit vessels. Data were drawn from the validated versions of two core reference documents: V.0.1 TIN Contacts EET Matched Companies and V.0.1 Matrix of EET vs Segments, both of which had been updated and finalized in coordination with project partners. It was mutually agreed that the datasets would be frozen as of Friday, May 13th, to ensure consistency in the subsequent analysis.

Based on these consolidated sources, the results of the matrix evaluation have been structured and are presented across the seven defined categories, reflecting the distinct regulatory and technical considerations for both newbuilds and retrofit fleet scenarios.

The domain of the results table presented is structured according to vessel segments, **(IWT), (SSS), and (OG), and classified under NB (New Buildings) and R(Retrofits).** Each (EET) has been independently evaluated across three critical dimensions: **Applicability (A), Feasibility (F), and (TRL)**, Additionally, the diagram acknowledges the existence of variables categorized as **Unverified Applicability (UA) and Unverified Feasibility (UF),** representing aspects where sufficient data for full evaluation was not available. These criteria are derived from a multidimensional source evaluation approach encompassing literature review, expert consultation, and stakeholder input via the TIN network.

- The evaluation is disaggregated by vessel segment and life-cycle context (NB vs. R), enabling targeted insight into implementation pathways.
- Applicability and Feasibility were assessed independently based on operational, spatial, regulatory, and economic considerations.
- TRL was evaluated based on available technological maturity indicators for each EET.

Furthermore, as of the final draft of this document, a number of EETs retain the designation *Unverified Applicability or Feasibility* due to:

- Incomplete or inconclusive data from existing sources.
- Situations where TRL is known, but applicability or feasibility could not be confirmed.
- Conversely, cases where a technology is contextually applicable and feasible, yet TRL data remains unverified or highly uncertain.

This distinction emphasizes the need for continued data refinement and stakeholder validation to improve the robustness of the matrix framework.

Category: Hydrodynamic Efficiency Improvements

Analysis for New buildings. The evaluation of Hydrodynamic Efficiency Improvements for new buildings shows strong data for OG and IWT fleets, enabling complete assessment. However, data for SSS is limited, leading to unverified applicability and feasibility scores. This highlights the need for further input and validation for SSS-specific implementations.

Discussion for New buildings. Although TRL scores are high for IWT and OG, partners must clarify each EET's TRL and explain feasibility and applicability in IWT newbuilds. Consideration of design constraints, operating environments, and cost factors is essential to justify deployment potential and guide future decisions within the IWT segment.

Table 6. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Hydrodynamic Efficiency Improvements category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
2. Hull Form Optimization	High	High	9	UA	UF	-	High	High	9
3. Air lubrication systems (ALS)	Moderate	Low	8	Moderate	Moderate	9	High	Moderate	9
4. Hull Surface Coatings & Low-Drag Paints	Moderate	Low	-	UA	UF	-	High	High	9
5. Bulbous Bow Optimization	Low	Low	-	UA	UF	-	High	High	9
6. Hull Openings and Skeg Shape Optimization	Moderate	Moderate	9	UA	UF	-	High	High	9
7. Trim & draft optimization	Moderate	Moderate	9	UA	UF	-	High	High	9
8. Variaton of block coefficient/lengthening	High	High	9	UA	UF	-	High	High	9

Analysis for Retrofits. The retrofit evaluation for Hydrodynamic Efficiency Improvements shows completed TRL assessments for OG and IWT. OG technologies received optimistic ratings due to abundant references and clearer feasibility. IWT data was more moderate, while SSS lacked sufficient partner input, resulting in limited or unverified applicability and feasibility results.

Discussion for Retrofits. Retrofit evaluations for SSS remain inconclusive due to missing or unverified data from partners. In IWT, while technologies appeared applicable, feasibility proved more limited due to technical constraints. This distinction across EETs underscores the importance of separately assessing applicability and feasibility to support realistic retrofit strategies.

Table 7. Data Sources and Readiness Levels for EETs in Retrofit vessels for the Hydrodynamic Efficiency Improvements category.

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
2. Hull Form Optimization	Moderate	Moderate	9	UA	UF	-	Low	Low	5 to 6
3. Air lubrication systems (ALS)	Low	Low	4	Moderate	Moderate	9	High	Moderate	9
4. Hull Surface Coatings & Low-Drag Paints	Moderate	Low	5 to 6	UA	UF	-	High	High	9
5. Bulbous Bow Optimization	Low	Low	4	UA	UF	-	Moderate	Moderate	9
6. Hull Openings and Skeg Shape Optimization	Low	Moderate	9	UA	UF	-	UA	UF	9
7. Trim & draft optimization	Moderate	Moderate	9	UA	UF	-	High	High	9
8. Variaton of block coefficient/lengthening	Moderate	Moderate	9	UA	UF	-	UA	UF	9

Category: Operations & Digital Optimization

Analysis for New buildings. For new buildings, the evaluation revealed stronger data availability and expert input for IWT and OG segments, with substantial reference support for SSS. The criteria-based assessments indicate a well-documented foundation, enabling clearer insights across most technologies within the Hydrodynamic Efficiency Improvements category.

Discussion for New buildings. Among the nine EETs assessed, about half demonstrate solid evaluation scores. However, EETs 9 and 10 raise concerns due to limited or unverified data on applicability and feasibility. These cases highlight the need for further validation and partner engagement to confirm their viability in newbuild contexts.

Table 8. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the operations and digital optimization category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
9. Hull Cleaning & Condition-Based Monitoring	Low	Low	4	UA	UF	-	High	High	9
10. Hull Protection based on Ultrasound tech	Low	Low	4	UA	UF	-	UA	UF	-
11. CPP pitch optimization and propeller performance	Moderate	Moderate	8	UA	UF	-	UA	UF	-
12. Weather routing systems speed/fuel optimization	High	High	5 to 6	UA	UF	-	High	High	9
13. Just-in-time (JIT) arrival strategies	Moderate	Moderate	7	Moderate	Moderate	7	Moderate	Moderate	7
14. Speed optimization (slow steaming)	High	High	5 to 6	High	High	9	High	High	9
15. Port Turnaround Time Reduction	High	High	5 to 6	High	Moderate	5 to 6	Moderate	Moderate	5 to 6
16. Cargo Load Factor Optimization	High	High	5 to 6	High	Moderate	5 to 6	Moderate	Moderate	5 to 6
17. Autopilot Upgrade and Adjustment	High	High	7 to 8	High	High	9	High	High	9

Analysis for Retrofits. Retrofit evaluations for Hydrodynamic Efficiency Improvements show strong alignment with newbuild data, especially for IWT and OG. Partner contributions were substantial, and the consistency between newbuild and retrofit findings suggests similar technical performance and documentation levels across most evaluated EETs.

Discussion for Retrofits. Despite promising evaluations, OG applicability and feasibility vary significantly among EETs. In contrast, SSS retrofits suffer from data gaps, limiting evaluation confidence. The IWT results underline distinctions between applicability and feasibility, reinforcing the necessity of nuanced assessments and targeted data collection for underexplored retrofit technologies.

Table 9. Data Sources and Readiness Levels for EETs in Retrofits vessels for the operations and digital optimization category.

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
9. Hull Cleaning & Condition-Based Monitoring	Low	Low	4	UA	UF	-	High	High	9
10. Hull Protection based on Ultrasound tech	Low	Low	4	UA	UF	-	UA	UF	9
11. CPP pitch optimization and propeller performa	Moderate	Moderate	9	UA	UF	-	UA	UF	-
12. Weather routing systems speed/fuel optimizat	High	High	5 to 6	UA	UF	-	High	High	9
13. Just-in-time (JIT) arrival strategies	Moderate	Moderate	7	Moderate	Moderate	7	Moderate	Low	9
14. Speed optimization (slow steaming)	High	High	5 to 6	High	High	9	High	High	7
15. Port Turnaround Time Reduction	High	High	5 to 6	Moderate	Moderate	5 to 6	Moderate	Low	9
16. Cargo Load Factor Optimization	High	High	5 to 6	Moderate	Moderate	5 to 6	Moderate	Low	5 to 6
17. Autopilot Upgrade and Adjustment	High	High	7 to 8	High	High	9	High	High	5 to 6

Category: Optimized Engineering Approaches

Analysis for New buildings. The IWT segment presents relevant data with moderate evaluations across most EETs. However, there is a clear lack of information for SSS and OG. The absence of data from these sectors suggests limited maturity or engagement of these EETs within newbuild applications, requiring further investigation.

Discussion for New buildings. Most EETs in the SSS and OG segments lack sufficient evaluation or input from partners, indicating low technological maturity or limited commercial traction in newbuild markets. This gap raises concerns about the readiness and applicability of these solutions for integration into newly constructed vessels.

Table 10. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the optimized engineering approaches category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
1. Onboard Carbon Capture and Storage (CCS) Systems	Low	Low	4	Moderate	Low	-	High	Moderate	5 to 6
18. Water-Emulsified Fuel Technology	Moderate	Moderate	8	High	Low	8	Moderate	Low	8
19. Main Engine Tuning & Optimization	High	High	7 to 8	UA	UF	-	UA	UF	-
20. Variable Frequency Drive (VFD) for speed control	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
21. Lightweight shipbuilding materials	Moderate	Moderate	5 to 6	High	High	8	Low	Low	4
22. Reduced Auxiliary Power Demand	High	High	8	UA	UF	-	UA	UF	-
23. Steam/heat plant improvements/optimization	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
24. Advanced HVAC & cooling systems	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-

Analysis for Retrofits. IWT retrofit evaluations show a compact but moderately reliable dataset. In contrast, there is minimal expertise or assessment for retrofitting within the SSS and OG sectors. The data scarcity suggests an overlooked domain or insufficient stakeholder involvement in retrofit-specific technological deployment assessments.

Discussion for Retrofits. Limited retrofit data may stem from regulatory gaps or confusion between retrofit and newbuild frameworks. Additionally, many EETs appear primarily developed for newbuild contexts, leaving retrofits underexplored. A clear lack of expert input on several EETs further complicates their validation for retrofit integration.

Table 11. Data Sources and Readiness Levels for EETs in Retrofit vessels for the optimized engineering approaches category

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
1. Onboard Carbon Capture and Storage (CCS) Systems	Low	Low	4	Low	Low	4	Moderate	Low	9
18. Water-Emulsified Fuel Technology	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
19. Main Engine Tuning & Optimization	High	High	7 to 8	UA	UF	-	UA	UF	-
20. Variable Frequency Drive (VFD) for speed control	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
21. Lightweight shipbuilding materials	Low	Low	5 to 6	Low	Low	5	Low	Low	5
22. Reduced Auxiliary Power Demand	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
23. Steam/heat plant improvements/optimization	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
24. Advanced HVAC & cooling systems	Low	Low	4	UA	UF	-	UA	UF	-

Category: Power Conversion, Electrification & Energy Devices

Analysis for New buildings. This category contains the highest number of EETs, making cross-comparison across IWT, SSS, and OG more complex. However, robust data and expert evaluations exist for IWT, and relevant input is found for OG. The SSS segment shows noticeable gaps in evaluation and source coverage.

Discussion for New buildings. The SSS segment lacks source data and TRL verification, limiting the evaluation of EET maturity. The rapid evolution and integration of new energy technologies complicate feasibility and applicability assessments, suggesting that dynamic advancements challenge consistent evaluation, particularly for SSS newbuild applications.

Table 12. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Power Conversion, Electrification & Energy Devices category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
25. Heaving Oscillating Systems	Low	Low	4	UA	UF	-	UA	UF	-
26. Full Electric Propulsion Concepts	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
27. Alternative Fuelled 2-S ICEs	Low	Low	5	Moderate	Moderate	5	High	High	5
28. Alternative Fuelled 4-S ICEs/Gensets	Moderate	Moderate	5 to 6	High	Moderate	5	High	High	5
29. Waste heat recovery systems (WHRS)	Low	Moderate	4	UA	UF	-	High	High	9
30. PEM fuel cells	High	Moderate	8	Moderate	Moderate	5 to 6	Moderate	Moderate	5 to 6
31. SOFC fuel cells	Moderate	Moderate	5 to 6	Moderate	Moderate	5 to 6	Moderate	Moderate	5 to 6
32. Other type of fuel cells	Low	Low	4	UA	UF	-	UA	UF	-
33. Energy storage systems (ESS) – lithium-ion batteries	High	High	9	UA	UF	-	UA	UF	-
34. Energy storage systems (ESS) – redox flow batteries (R	Low	Low	4	UA	UF	-	UA	UF	-
35. Onshore Power Supply [OPS]	High	Moderate	5 to 6	High	High	9	High	Low	9
36. Low-Loss Power Distribution Systems	High	High	9	UA	UF	-	UA	UF	-
37. Shaft Generator PTI, PTO, PTI/PTO	Moderate	Moderate	5 to 6	High	High	9	High	High	9
65. Onboard Power Systems and Power Electronics	UA	UF	-	UA	UF	-	UA	UF	-
66. DC Grid technologies	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
67. Electric propulsion systems and thrusters	High	High	9	UA	UF	-	UA	UF	-
68. Energy Management Systems (EMS)	High	High	9	High	High	9	High	High	9

Analysis for Retrofits. IWT retrofit-related EETs offer compact yet low-TRL data, though supported by higher-quality sources and evaluation. In contrast, SSS and OG segments lack adequate information.

Discussion for Retrofits. SSS and OG segments demonstrate insufficient data and evaluations for key energy technologies. The disconnect may arise from poor integration of retrofit solutions with rapidly evolving energy systems.

Table 13. Data Sources and Readiness Levels for EETs in retrofit vessels for the Power Conversion, Electrification & Energy Devices category

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
25. Heaving Oscillating Systems	Low	Low	4	UA	UF	-	UA	UF	-
26. Full Electric Propulsion Concepts	Moderate	Low	5 to 6	UA	UF	-	UA	UF	-
27. Alternative Fuelled 2-S ICEs	Low	Low	4	Low	Low	5	Low	Low	5
28. Alternative Fuelled 4-S ICEs/Gensets	Moderate	Moderate	5 to 6	High	High	5	High	High	5
29. Waste heat recovery systems (WHRS)	Low	Low	4	UA	UF	-	High	High	9
30. PEM fuel cells	Moderate	Moderate	8	Moderate	Low	5 to 6	UA	UF	-
31. SOFC fuel cells	Low	Low	4	Low	Low	4	UA	UF	-
32. Other type of fuel cells	Low	Low	4	UA	UF	-	UA	UF	-
33. Energy storage systems (ESS) – lithium-ion batteries	High	High	8	UA	UF	-	UA	UF	-
34. Energy storage systems (ESS) – redox flow batteries	Low	Low	4	UA	UF	-	UA	UF	-
35. Onshore Power Supply [OPS]	High	Moderate	5 to 6	High	High	9	High	Low	9
36. Low-Loss Power Distribution Systems	UA	UF	-	UA	UF	-	UA	UF	-
37. Shaft Generator PTI, PTO, PTI/PTO	Moderate	Low	5 to 6	UA	UF	-	High	High	9
65. Onboard Power Systems and Power Electronics	UA	UF	-	UA	UF	-	UA	UF	-
66. DC Grid technologies	Moderate	Low	5 to 6	UA	UF	-	High	High	9
67. Electric propulsion systems and thrusters	High	High	8	UA	UF	-	High	High	9
68. Energy Management Systems (EMS)	High	High	8	High	High	9	High	High	9

Category: Propeller & Propulsion Optimization

Analysis for New buildings. The Propeller and Propulsion Optimisation category holds the highest number of references and evaluations, strongly supported by TIN partners and academic–industry sources. SSS and OG segments show high TRL and robust readiness, while IWT presents compact but sufficient data confirming feasibility and applicability across all EETs.

Discussion for New buildings. While the TRL assessments for SSS and OG appear high, a critical review of their scoring against the defined evaluation criteria is necessary. Similarly, IWT ratings must be validated to ensure consistency and accuracy in reflecting the true technological maturity within this advanced category.

Table 14.Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Propeller & Propulsion Optimization category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
39. Post-swirl ESD Contra-rotating propellers (CRP)	Low	Moderate	5	High	High	9	High	High	9
40. Pre-swirl ESD Wake Equalizing Ducts (WEDs)	Low	Low	4	High	High	9	High	High	9
41. Pre-swirl ESD ESD Fins	Low	Moderate	5 to 6	High	High	9	High	High	9
42. Manoeuvring devices (e.g. Gate rudder)	Moderate	Moderate	5 to 6	High	High	9	High	High	9
43. Propeller Nozzle (e.g. Kort)	High	High	9	High	High	9	High	Moderate	9
44. Post-swirl ESD PBCF (Propeller Boss Cap Fins)	Low	Low	4	High	High	9	High	High	9
45. Post-swirl ESD Grim Vane Wheel	Low	Low	4	High	High	9	High	High	9
46. Pulling Azimuth Thrusters	Moderate	Moderate	5 to 6	High	High	9	High	High	9
47. Propeller-Retrofitting Advanced propeller Blade Sections	Low	Low	4	UA	UF	-	UA	UF	-

Analysis for Retrofits. Retrofit evaluations in this category indicate high TRL and feasibility for OG and SSS segments. IWT exhibits a much lower but completed evaluation dataset. The contrast suggests limited retrofit integration for IWT, despite the category's technological maturity across broader maritime sectors.

Discussion for Retrofits. This raises questions: do EETs in this category inherently require fewer retrofits due to their advanced maturity? Or has the evaluation disproportionately emphasized OG and SSS, overlooking IWT-specific challenges? Clarifying these differences is key to aligning retrofit feasibility with segment-specific operational realities.

Table 15.Data Sources and Readiness Levels for EETs in Retrofit vessels for the Propeller & Propulsion Optimization category.

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
39. Post-swirl ESD Contra-rotating propellers (CRP)	Low	Low	4	High	High	9	High	High	9
40. Pre-swirl ESD Wake Equalizing Ducts (WEDs)	Low	Low	4	High	High	9	High	High	9
41. Pre-swirl ESD ESD Fins	Low	Low	4	High	High	9	High	High	9
42. Manoeuvring devices (e.g. Gate rudder)	Low	Low	4	High	High	9	High	High	9
43. Propeller Nozzle (e.g. Kort)	High	High	9	High	High	9	High	Moderate	9
44. Post-swirl ESD PBCF (Propeller Boss Cap Fins)	Low	Low	4	High	High	9	High	High	9
45. Post-swirl ESD Grim Vane Wheel	Low	Low	4	High	High	9	High	High	9
46. Pulling Azimuth Thrusters	Low	Low	9	High	High	9	High	High	9
47. Propeller-Retrofitting Advanced propeller Blade Secti	Low	Low	4	UA	UF	-	High	High	9

Category: Renewable Energy Integration

Analysis for New buildings. This is the second most thoroughly referenced category for OG and SSS, with strong data and evaluations. However, IWT lacks sufficient information, and TRL assessments are missing. The imbalance highlights a gap in evaluating renewable technologies' relevance and readiness in inland shipping applications.

Discussion for New buildings. SSS shows promising applicability and feasibility for several EETs in this category, yet TRL data remains absent or unverified. This inconsistency raises concerns about evaluation completeness and necessitates revalidation to ensure TRL levels align with the claimed deployment potential, especially for newbuild integration.

Table 16. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Renewable Energy Integration category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
38. Hydrofoil-Based Wave Energy Converters	Low	Low	3	UA	UF	-	UA	UF	-
48. WASPs - Soft Sails	Low	Low	4	Moderate	Moderate	9	Moderate	Moderate	9
49. WASPs - Flettner Rotors (Magnus Effect Rotors)	Low	Low	4	Moderate	High	9	High	High	9
50. WASPs - Rigid Wing Sails	Low	Low	4	Moderate	High	9	High	High	9
51. WASPs - Kite Propulsion Systems	Low	Low	4	Moderate	Moderate	9	High	Moderate	9
52. WASPs - Suction Wings (Ventifoils)	Low	Low	4	High	High	9	High	High	9
53. WASPs - Turbosails	Low	Low	4	Moderate	Moderate	9	High	High	9
54. WASPs - Dynarig (DynaRig) System	Low	Low	4	Moderate	Moderate	9	High	High	9
55. SOLAR - Photovoltaic (PV) Panels for Ships	Moderate	High	5 to 6	Moderate	High	6	Low	Moderate	6

Analysis for Retrofits. Only IWT shows completed evaluation, albeit with minimal data and no TRL scoring. OG vessels exhibit high TRL levels, yet their applicability and feasibility have not been assessed through TIN or expert inputs. SSS also lacks supporting data or stakeholder validation for retrofitting these EETs.

Discussion for Retrofits. There is a clear need to revisit the assessments for SSS and OG. Despite OG's high TRL indications, no applicability or feasibility evaluations are recorded. This discrepancy calls into question whether these EETs were overlooked in partner consultations or misclassified during the matrix scoring process.

Table 17.Data Sources and Readiness Levels for EETs in Retrofit vessels for the Renewable Energy Integration category.

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
38. Hydrofoil-Based Wave Energy Converters	Low	Low	4	UA	UF	-	High	High	9
48. WASPs - Soft Sails	Low	Low	4	UA	UF	-	High	High	9
49. WASPs - Flettner Rotors (Magnus Effect Rotors)	Low	Low	4	UA	UF	-	High	High	9
50. WASPs - Rigid Wing Sails	Low	Low	4	UA	UF	-	High	High	9
51. WASPs - Kite Propulsion Systems	Low	Low	4	UA	UF	-	UA	UF	6
52. WASPs - Suction Wings (Ventifoils)	Low	Low	4	UA	UF	-	High	High	9
53. WASPs - Turbosails	Low	Low	4	UA	UF	-	UA	UF	7 to 8
54. WASPs - Dynarig (DynaRig) System	Low	Low	4	UA	UF	-	High	High	9
55. SOLAR - Photovoltaic (PV) Panels for Ships	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	5

Category: Sustainable, Climate-Neutral & Low-Emission Fuels

Analysis for New buildings. This category presents strong evaluation coverage across IWT, SSS, and OG. IWT shows a high number of evaluated EETs, while OG stands out with elevated TRL levels. The completeness of data underscores significant progress in fuel innovation, though gaps remain in academic support for SSS implementation.

Discussion for New buildings. While expert suggestions support SSS evaluations, academic literature and TRL validation are missing or weak. This discrepancy raises concerns about the robustness of SSS fuel-related assessments. A revaluation is required to verify TRL accuracy and clarify the applicability context within this maritime segment.

Table 18. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Sustainable, Climate-Neutral & Low-Emission Fuels category.

Energy Efficiency Technology (EET)	A(IWT-NB)	F(IWT-NB)	TRL (IWT-NB)	A(SSS-NB)	F(SSS-NB)	TRL (SSS-NB)	A(OG-NB)	F(OG-NB)	TRL (OG-NB)
56. Fuel Reforming/Cracking	UA	UF	-	UA	UF	-	Moderate	Low	9
57. Methanol	Moderate	Moderate	5 to 6	High	High	7 to 8	Moderate	Moderate	7 to 8
58. Biomethane	Moderate	Low	5 to 6	High	High	9	Moderate	Moderate	9
59. Ammonia	Moderate	Moderate	5 to 6	Moderate	High	5	High	High	5
60. Biodiesel	Moderate	Moderate	7	High	High	9	High	High	9
61. Synthetic Biofuels (Power-to-Liquid E-Fuels)	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
62. Hydrotreated Vegetable Oil (HVO - Renewable Diesel)	High	High	8	High	High	9	High	High	9
63. Hydrogen	High	Moderate	7	Moderate	Moderate	6	Moderate	Moderate	6
64. Synthetic e-fuels	UA	UF	-	UA	UF	-	UA	UF	-

Analysis for Retrofits. IWT retrofits show nearly full data coverage yet lack TRL scoring. OG demonstrates moderate TRL levels but without feasibility or applicability evaluations. SSS retrofit evaluations are unverified, likely due to the novel nature of these fuels, suggesting potential incompatibility with existing systems or insufficient integration evidence.

Discussion for Retrofits. There is uncertainty regarding whether these fuels can realistically be adopted in existing IWT and OG vessels. It is essential to consult experts further or formally acknowledge the current lack of data and practical references, rather than assume retrofit feasibility for such emerging technologies

Table 19. Data Sources and Readiness Levels for EETs in Newbuilding vessels for the Sustainable, Climate-Neutral & Low-Emission Fuels category.

Energy Efficiency Technology (EET)	A(IWT-R)	F(IWT-R)	TRL (IWT-R)	A(SSS-R)	F(SSS-R)	TRL (SSS-R)	A(OG-R)	F(OG-R)	TRL (OG-R)
56. Fuel Reforming/Cracking	UA	UF	-	UA	UF	-	High	High	9
57. Methanol	Moderate	Low	5 to 6	UA	UF	-	UA	UF	-
58. Biomethane	Low	Low	4	UA	UF	-	High	High	9
59. Ammonia	Low	Low	4	UA	UF	-	UA	UF	6
60. Biodiesel	Low	Low	4	UA	UF	-	UA	UF	-
61. Synthetic Biofuels (Power-to-Liquid E-Fuels)	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
62. Hydrotreated Vegetable Oil (HVO - Renewable Diesel	High	High	8	UA	UF	-	UA	UF	-
63. Hydrogen	Moderate	Moderate	5 to 6	UA	UF	-	UA	UF	-
64. Synthetic e-fuels	UA	UF	-	UA	UF	-	High	High	9

The V.0.1 Matrix of EET vs Segments document presents a consolidated assessment based on multidimensional source evaluation criteria, established through a triangulated approach that includes a comprehensive literature review, targeted input from sectoral experts and consultants, and insights from the TIN Network Advisory Group, supported by structured discussion meetings. This methodological framework, developed under Task 2.1, has enabled a validated and consensus-driven evaluation of more than 90% of the proposed EETs.

The analysis reveals that new buildings have received more extensive data coverage than retrofit vessels, underscoring a clearer regulatory and technological direction in that segment. For new buildings, the four categories with the highest number of references and evaluations are:

1. Propeller, Propulsion, and Optimisation,
2. Renewable Energy Integration,
3. Operational and Digital Optimisation, and
4. Sustainable, Climate-Neutral, and Low-Emission Fuels.

For retrofits, the most data-rich categories are:

1. Propeller, Propulsion, and Optimisation,
2. Operational and Digital Optimisation,
3. Power Conversion and Energy Devices, and
4. Hydrodynamic Efficiency Improvements.

Notably, the IWT and OG segments have received the most comprehensive input and re-evaluation, both from partners and across the available literature, providing a strong evidence base. This contributes significantly to building continuity and coherence in the assessment process, forming a robust link to Task 2.2, which will further elaborate performance metrics and decision-support tools.

Overall, the evaluation of 68 EETs across 7 categories confirm strong coherence and provides a technically grounded foundation to further quantify each EET's applicability, feasibility, and TRL through performance-based metrics in the next project phase.

Chapter 5 EET Taxonomy and Priority Evaluation

The establishment of a taxonomy for (EETs) is essential. NTNU proposes this structured classification as a foundational element of Work Package 2 (WP2) to ensure methodological coherence, traceability, and scalability in assessing technological solutions across diverse vessel types and operational profiles.

A well-defined EET taxonomy, organized into categories, subcategories, specific technologies (EETs), and corresponding metrics, enables a harmonized approach for mapping the maturity, applicability, and feasibility of each technology. This categorization supports the creation of a robust evaluation framework that is adaptable to both newbuild and retrofit contexts and sensitive to the particular needs of different maritime segments (IWT, SSS, OG).

The alignment of the taxonomy with regulatory instruments (e.g., Fit-for-55, EU Taxonomy for Sustainable Activities) ensures that the selection and prioritization of EETs respond not only to technical potential but also to policy relevance and market readiness. Furthermore, the taxonomy enhances interoperability across tasks and work packages by:

- Defining a shared vocabulary for technical and regulatory discussions,
- Supporting comparative analysis of EETs across vessel types and operational regimes,
- Structuring data collection and stakeholder engagement, and
- Guiding the development of metrics that are meaningful and context specific.

This taxonomy will serve as the reference backbone for WP2.0's efforts to evaluate the most promising EETs, identify gaps, and recommend pathways for integration within the maritime fleet transition. Establishing a prioritized list of EETs within a structured taxonomy ensures that further assessments, particularly under Task 2.1 and 2.2, are both transparent and

reproducible—ultimately contributing to more informed decision-making and effective decarbonization strategies.

5.1 First Category – Functional System-Level Domains (Where Technology Is Applied)

The first foundational layer is based on Functional System-Level Domains, which define where each EET is applied onboard a vessel. This system-level structure reflects the reality of ship design architecture and operational logic, ensuring alignment with how shipowners, classification societies, engineers, and international regulatory frameworks (e.g., IMO) assess energy interventions.

These five domains represent the primary onboard functional systems, providing a structured, operationally meaningful basis to categorize technologies. Stakeholders are thus guided to first consider the question: "Where is this technology applied?", enabling consistency across technical evaluation, design integration, and policy relevance.

This categorization builds upon methodologies proposed in the DNV Maritime Energy Efficiency Report (DNV, 2025) [4] and is directly supported by insights from the current EET evaluation matrix developed in WP2.0, which integrates literature, expert consultation, and TIN partner feedback.

Table 20. Proposed Taxonomy Coding Framework

Category Name	Proposed Taxonomy Coding	Why It's Used
1.0. Energy Consumers (EC)	EC-1.0.	Focuses on systems that consume energy, hVAC, lighting, and onboard power electronics. These are critical for reducing onboard demand.
2.0. Energy Harvesting (EH)	EH-2.0.	Involves recovering or capturing energy (wind, solar, wave). These are often additive technologies that reduce reliance on traditional and /or alternatives fuel.
3.0. Propulsion and Hull (PH)	PH-3.0.	Covers hull design, coatings, and propulsion systems, critical for reducing hydrodynamic resistance and improving fuel economy.
4.0. Machinery & Power Systems (MP)	MP-4.0	Involves auxiliary and engine room systems, fans, engines, pumps, boilers—that can be optimized for better performance.
5.0. Operational Optimization (OO)	OO-5.0.	Encompasses voyage planning, routing, cargo optimization, and port turnaround, offering high ROI with digital tools and coordination.

[4] DNV (2025). Maritime Energy Efficiency: Technologies and Measures for GHG Reduction. Retrieved from https://www.dnv.com/maritime/publications/energy-efficiency-report-download/

5.2 Second Subcategory – Technology Class or Optimization Focus (What It Targets)

The categories used for classifying Energy Efficiency Technologies (EETs) were initially described in the Grant Agreement (GA), specifically in Step 2 (Part B, page 10 of 34), where a comprehensive framework and pre-identified EETs were outlined. While the overarching category structure remains unchanged, the relocation and reassignment of specific technologies across categories is an ongoing process. As the evaluation evolves, certain EETs have been repositioned to better reflect their primary functions or cross-cutting applications. This iterative refinement supports a more accurate alignment with operational realities and enhances the taxonomy's usefulness for analysis and decision-making.

The second subcategory organizes EETs by their core function and optimization goal, highlighting what each technology targets to enhance energy efficiency. This categorization supports designers and fleet managers in evaluating system compatibility, cost, and risk, enabling more informed decisions. It provides clarity on performance impact, aligning technical function with practical application in ship operations. The seven categories used were selected and confirmed by the TIN Committee up to Task 2.1, ensuring consensus and alignment with real-world applicability and expert review.

Table 21. Proposed Taxonomy Coding Framework for the subcategory.

Subcategory Name	Proposed Taxonomy Coding	Why It's Used
Hydrodynamics Efficiency Improvements	[HEI]	Focused on reducing vessel resistance, such as hull coatings, CCS, or hull form tweaks.
Operations and Digital Optimization	[ODO]	Encompasses software- and data-driven voyage, routing, and behaviour-based efficiencies.
Optimised Engineering Approaches	[OEA]	Covers design/engineering improvements to reduce auxiliary loads or improve energy use. (e.g., WHRS, VFDs)
Power Conversion, Electrification, and Energy Devices	[PEE]	Focuses on electrical and hybrid systems, including propulsion, storage, and distribution. (e.g. Battery Energy Storage Systems (BESS))
Propeller and Propulsion Optimization	[PPO]	Covers devices that reduce propulsion losses (e.g., ESDs, optimized propellers, CPPs, CRPs)
Renewable Energy Integration	[REI]	Captures wind, solar, wave technologies that provide alternative propulsion or power. (e.g., wind assisted propulsion systems, photovoltaic solar panels)
Sustainable, Climate-Neutral and Low-Emission Fuels	[SCE]	Groups technologies by fuel type, combustion method, or fuel flexibility. (e.g., hydrogen fuel cells, methanol reformers)

The proposed taxonomy enables a structured evaluation of EETs by focusing on identification, communication, and facilitation of relevant metrics. While second-level subcategories may overlap across multiple first-level categories, this flexibility supports practical application. The taxonomy guides the assessment of economic viability, energy transition alignment, and

environmental impact, serving as a dynamic tool for strategic planning, regulatory compliance, and technology adoption across diverse vessel types and fleet levels.

The classification of Energy Efficiency Technologies (EETs) into functional categories is based on their core mechanism of action and impact area onboard a vessel. This structured approach ensures clarity, technical relevance, and alignment with industry logic. The criteria for assigning EETs to categories are explained and showed in the table 22.

Table 22. Proposed matching criteria for the subcategory.

1st Category	2nd Subcategory	Proposed Taxonomy Coding	Matching Criteria
Energy Consumers	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	Technologies that convert, store, or manage energy flow onboard. Focus on electrical systems.
	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	Fuels or energy carriers with reduced GHG emissions. Includes production/storage systems.
Energy Harvesting	Renewable Energy Integration	EH-2.0. - [REI]	Systems capturing external energy (wind, solar, waves) for propulsion or auxiliary power.
Propulsion & Hull	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	Technologies improving thrust efficiency or propeller design.
	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	Hull-focused solutions reducing drag/resistance.
Machinery & Power Systems	Optimised Engineering Approaches	MP-4.0 - [OEA]	Material/design innovations reducing energy demand in ship systems.
Operational Optimization	Operational and Digital Optimisation	OO-5.0. - [ODO]	Software, AI, or process improvements for voyage efficiency.

5.3 Third Energy Efficiency Technology (EET) Category – Specific Technologies

The continuous refinement of the Energy Efficiency Technologies (EETs) list, including the emergence of new solutions or removal of less viable ones, is explicitly supported in the Grant Agreement under Step 3 (Part B, page 11). This process is enabled by the establishment of the Technologies Innovation Network (TIN), an external board composed of EET providers. TIN plays a critical role in guiding the selection, evaluation, and integration of EETs throughout the project. Given that several EETs are already in commercial use while others remain technically complex or in earlier development stages, the TIN ensures real-time feedback and expert insight to maintain the relevance and quality of the evolving EET catalogue. This mechanism guarantees that the FLEETfor55 project remains adaptive and technologically current.

(EET) Category – Specific Technologies **was prominently highlighted in the Matrix Version V.0.1 and agreed upon by consensus among the project partners**. While this categorization remains open for future refinement or merging EET, it currently provides a crucial granular

level of detail. It identifies individual technologies, systems, or methods clearly and consistently, enabling users to accurately map real-world solutions to system-level goals, regulatory frameworks such as the IMO GHG Strategy, and technical feasibility assessments. This detailed classification supports targeted evaluation and practical application of energy efficiency measures.

Power Conversion, Electrification, and Energy Devices (PEE)

Definition. Power Conversion, Electrification, and Energy Devices refer to technologies aimed at improving the efficiency, distribution, and conversion of electrical or mechanical power onboard vessels.
Matching Criteria:

- Involves electrical propulsion or power electronics systems.
- Integrates energy storage systems (ESS).
- Enhances onboard power generation or distribution, including converters and transformers.

Sustainable, Climate-Neutral and Low Emission Fuels (SCE)

Definition. Sustainable, Climate-Neutral, and Low Emission Fuels encompass technologies and systems that enable the use, reforming, or production of low-carbon fuels to reduce environmental impact and support decarbonization efforts.

Matching Criteria:

- Innovations related to alternative fuels such as hydrogen, ammonia, biofuels, and synthetic fuels.
- Engines adapted or modified to operate on these alternative fuels.
- Fuel reforming and cracking technologies that convert or process fuels for cleaner combustion.

Propeller and Propulsion Optimization (PPO)

Definition. Propeller and Propulsion Optimisation technologies aim to enhance propulsive efficiency by improving propeller hydrodynamics and optimizing thrust generation. These technologies contribute to reduced fuel consumption and emissions by maximizing the conversion of engine power into effective vessel movement.

Matching Criteria:

- Modifications to propeller design or control systems.
- Enhancements that improve thrust efficiency or optimize flow conditions around the propeller.
- Retrofits targeting improved performance of the shaft line or propeller blades

Operational and Digital Optimization (ODO)

Definition. Operational and Digital Optimisation includes technologies that improve vessel efficiency through software, data, and procedural tools.

Matching Criteria:

- Voyage planning, routing, or scheduling
- Autopilot, EMS, or onboard analytics
- Speed and arrival-time optimisation

Optimized Engineering Approaches (OEA)

Definition. Optimised Engineering Approaches involve structural or system-level design enhancements that improve overall vessel energy efficiency.

Matching Criteria:

- Use of lightweight materials and structures
- Optimisation of HVAC and thermal systems
- Integration of heat recovery or steam enhancement technologies

Renewable Energy Integration (REI)

Definition. Integration of renewable energy refers to the adoption of technologies that harness natural energy sources such as wind, solar, wave, or hydro, to supplement or replace conventional onboard energy systems. This includes systems that directly support propulsion or contribute to auxiliary power needs, improving overall vessel efficiency.

Matching Criteria:

- Wind-assisted propulsion systems (e.g., rotor sails, kites, wings)
- Renewable energy converters (solar panels, wave and hydro generators)
- Integration of renewable sources into onboard power architecture

Hydrodynamic Efficiency Improvements (HEI)

Definition. Enhancements to the hull and appendages focused on minimizing hydrodynamic drag, thereby improving vessel performance and reducing fuel consumption.

Matching Criteria:

- Optimized hull shapes and geometry

- Advanced drag-reducing coatings
- Air lubrication technologies and Innovative skeg and appendage designs

5.4 Forth Category – Performance & Impact Metrics (Now 5 Types)

To enhance and refine the taxonomy, each (EET) should be evaluated through a robust set of multi-criteria performance metrics. These metrics ensure that the taxonomy structure goes beyond simple classification and becomes a practical decision-making tool by assessing each EET's applicability, feasibility, and sustainability within real-world maritime contexts. The evaluation should include:

- Operational factors
- Maintenance requirements
- Environmental impact
- Social implications
- Economic viability

By measuring technical maturity (TRL), compatibility, cost-effectiveness, and sustainability, stakeholders can prioritize technologies that deliver meaningful energy savings while aligning with regulatory and market demands, making the taxonomy a dynamic and actionable framework.

Table 23. Proposed matching criteria for the 4th subcategory metrics for each EET.

4th Subcategory -Metric Type	**Proposed Taxonomy Coding**	Description
Operational	[Ope]	Real-world functional performance: efficiency under different loads, fuel consumption per NM, uptime, etc.
Maintenance	[Man]	Costs and logistics related to servicing, inspection cycles, availability of spare parts, complexity of repairs.
Environmental	[Env]	GHG reductions (CO_2e), SOx/NOx/PM emissions, lifecycle footprint, and potential for compliance with IMO/EU targets.
Social	[Soc]	Crew training needs, workload, safety implications, comfort, and effects on work-life balance.
Economical	[Eco]	CAPEX, OPEX, payback period, Return on Investment (ROI), Net Present Value (NPV), fuel cost savings, scalability.

Priority evaluation of EETs should balance data availability, operational parameters, literature review, and TRL to assess maturity and applicability. Crucially, it must align with the specific interests and needs of companies, ensuring practical relevance. This approach guarantees that prioritization supports both technological readiness and real-world industry demand for effective deployment and adoption. The full **taxonomy structure proposed is detailed in Appendix B**, organizing the 68 EETs across seven categories as structured in FLEETfor55. Although the Trondheim conference later revised the count to 67 EETs, the original seven

categories remain unchanged, ensuring consistency and clarity in the classification approach up to this report

Chapter 6 Stakeholder & Industry Input (TIN, EAB)

The Excel document *TIN_Contacts & Status_Matched Companies V.0.1*, updated as of Friday, May 13th, reflects the evolving industrial context of the FLEETfor55 project. As the stakeholder network expands, this version marks a key milestone by documenting 127 companies that have been identified and considered within the project as potential contributors to one or more of the 68 Energy Efficiency Technologies (EETs) outlined to date. This analysis considers input up to Task 2.1 and offers a fleet-level overview, quantifying company engagement across categories and specific EETs. By interpreting these findings, we gain valuable insights into the industry's current positioning, strategic priorities, and alignment with the proposed EET taxonomy. This understanding is critical to guiding the next phases of technical evaluation and policy alignment.

Category-Level Analysis and Results

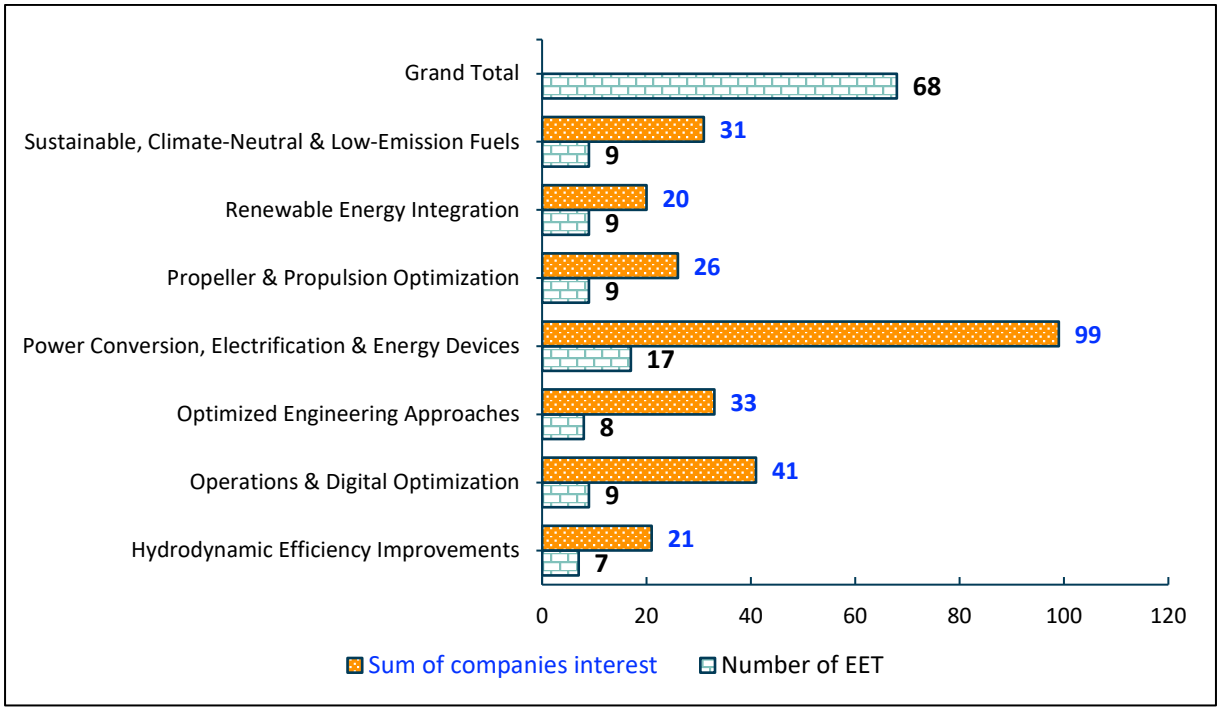

Figure 2. Bar chart of category level analysis.

The category-level analysis considered the distribution of the 68 EETs across the seven predefined categories, as detailed in the previous sections. As illustrated in Figure 2, the bar chart highlights that the category Power Conversion, Electrification, and Energy

Devices contains the highest number of EETs, with 17 technologies. The remaining categories each include between 7 and 9 EETs, showing a relatively balanced distribution.

From an industry interest perspective, the current list includes only a limited number of representative companies (typically 2–3) for certain technologies, rather than a comprehensive mapping of all potential contributors. This partial representation may lead to a misleading impression of low interest, which does not accurately reflect the actual relevance or market potential of some Energy Efficiency Technologies (EETs). Similar underrepresentation is likely present across other technologies as well. Despite this limitation, the available dataset still reveals discernible patterns and behaviours in industry engagement. Summing the number of companies expressing interest per EET at the category level suggests a form of prioritisation within the sector, offering a meaningful foundation for further exploration of the EET landscape aligned with perceived industry needs and preferences.

Moreover, the EET categorisation matrix is undergoing continuous refinement, with technologies being regularly reviewed and reallocated to better reflect their functions and applications. As more companies are identified and added to the analysis, the industry interest landscape is expected to evolve. Therefore, while current findings show concentrated engagement in categories such as Power Conversion, Electrification and Energy Devices, and Operation and Digital Optimisation, these trends must be interpreted with caution. The category-based analysis is a useful tool for identifying emerging behavioural patterns, but it remains only one component of a broader and dynamic analytical process, one that must remain flexible and responsive as technological scopes and industrial participation continue to develop.

EET-Level Analysis and Results

This section provides a detailed analysis of each (EET) based on the number of companies expressing direct interest. The evaluation considered all 68 EETs and mapped their relevance by quantifying industrial engagement. The analysis reveals that (OPS) is the most in-demand EET, followed closely by Onboard Power Systems and Power Electronics, and Energy Management Systems (EMS),each attracting interest from 11 companies. Additional EETs showing strong engagement include Hydrogen-Based Technologies and Energy Storage Batteries, rounding out the top 10 technologies. These top 16 EETs alone account for approximately 50% of total company interest, indicating a clear industry alignment around specific, high-impact technologies.

As shown in Figure 3, the distribution of interest across EETs highlights a strategic pattern that can guide project prioritization. Based on these results, and corroborated by literature review and Technology Readiness Level (TRL) assessment, it is recommended to prioritise the top 15 EETs. This approach aligns industrial relevance with technological feasibility, helping ensure impactful and scalable outcomes in the upcoming phases of the project.

Conversely, for EETs with fewer than three companies expressing interest, it is necessary to complement this input with a techno-economic assessment and literature review. This will help determine whether the low interest stems from technological immaturity, market conditions, or limited awareness. For EETs with four or more interested companies, a higher prioritisation is justified, particularly if supported by robust academic and industry data.

It is also important to clarify that the analysis is conducted at the fleet level, meaning it reflects aggregated interest and potential deployment across entire fleets, not individual vessel applications. This perspective ensures that the selected EETs are scalable, broadly applicable, and aligned with the sector-wide goals of reduce emissions, cost-efficiency, and operational feasibility.

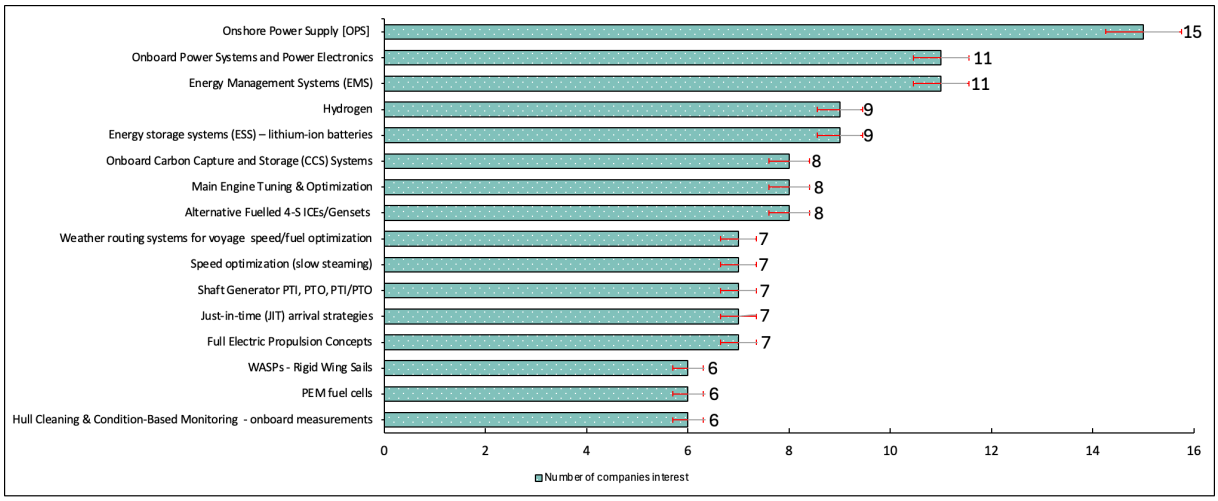

Figure 3. EETs with the Highest Industry Engagement: Bar Chart Analysis

The analysis illustrated in Figure 4 highlights three distinct levels of participation among the 68 identified Energy Efficiency Technologies (EETs). Notably, 16 EETs account for approximately 49% of total company participation, indicating a strong concentration of interest. In contrast, 27 EETs correspond to 37% of participation, while the remaining 25 EETs reflect only 15% of company involvement. This distribution suggests a clear prioritisation pattern within the sector. The 16 highly engaged EETs, also detailed in Figure 3, represent only 24% of the total EETs yet attract nearly half of the companies involved in the project. This demonstrates their centrality to the industry's current strategic focus and underscores the relevance of analysing the categories to which these technologies belong, as they likely drive the most immediate innovation and adoption efforts within FLEETfor55.

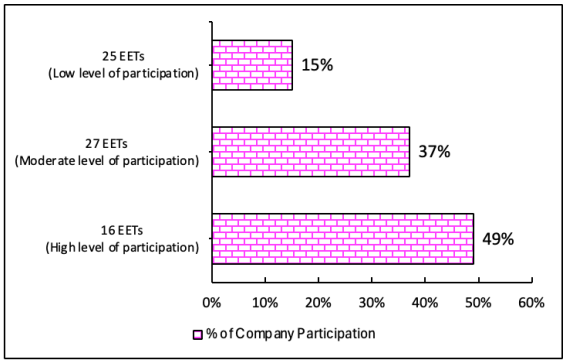

Figure 4. Three levels of participation based on company interest per EET

Company-Level Analysis and Results

Understanding that the list of potential contributors, EET providers, and project partners is continuously evolving, the number of companies expressing interest in specific Energy Efficiency Technologies (EETs) is likely to change over time. As shown in Figure 5, approximately 76 companies have currently expressed interest in at least one EET. While this number may vary with the ongoing refinement of inputs, the current data already reveal a clear pattern: a small group of 16 EETs out of the total 68 concentrates nearly 50% of total

company participation. This indicates a strong convergence of interest around a subset of high-priority technologies.

The company-level analysis highlights the varying degrees of engagement among organizations evaluating and implementing EETs across their fleets. Some stakeholders show broad interest, engaging with over a dozen EETs, while others concentrate on a smaller set of 1 to 3 technologies. These focused interests often reflect specific operational needs, market niches, or targeted innovation strategies, and should not be underestimated. Such diversity in engagement reinforces the importance of a fleet-level assessment approach, which supports scalable, comparable, and operationally relevant deployment of technologies across similar vessel types and use cases.

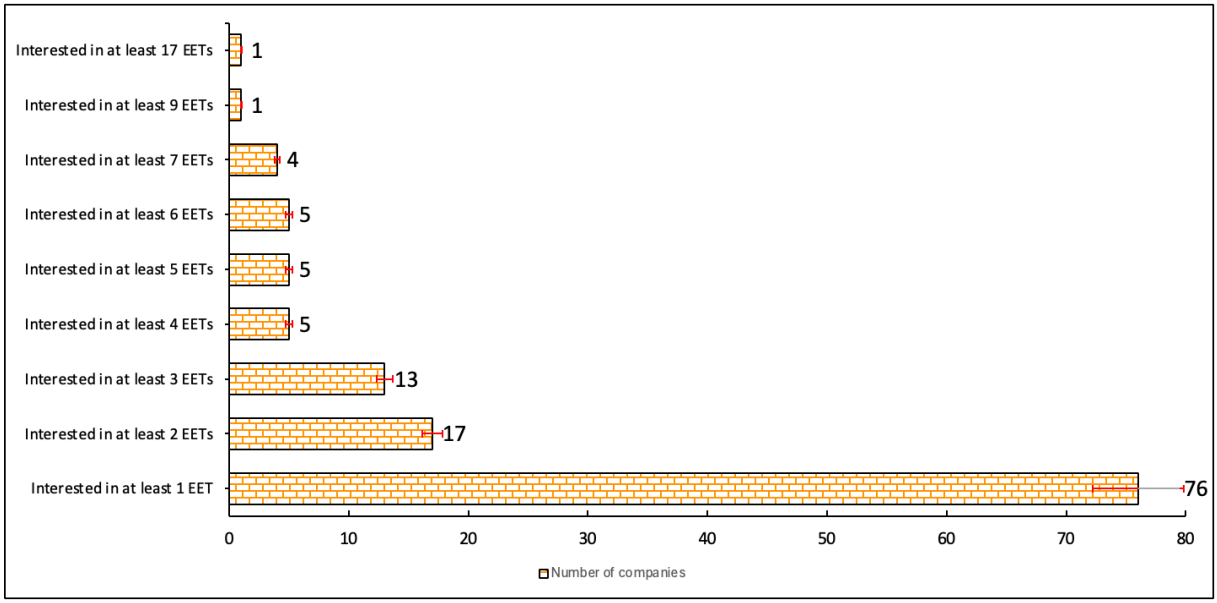

Figure 5. Bar chart of company level analysis

The concentration of EET interest within a small group of companies allows for detailed evaluation and potentially faster validation of technologies. However, this focus may inadvertently sideline the broader pool of contributors—representing over 50% of the companies—whose diverse input is equally critical. To avoid bias and ensure balanced outcomes, it is essential to maintain an inclusive approach that integrates both leading players and underrepresented but highly relevant stakeholders.

Chapter 7 Discussion and Trends

- Methodological Justification and Limitations of PRISMA

The selection of the PRISMA methodology, a structured approach for conducting systematic reviews and meta-analyses was a deliberate and technically justified decision within the

FLEETfor55 project to ensure traceability, reproducibility, and academic rigor in the evaluation of (EETs). However, while PRISMA is highly effective for literature-based syntheses, it presents notable limitations when applied to a context like FLEETfor55, where many criteria extend beyond academic literature and instead rely heavily on expert judgment, consultant evaluation, industry perception, evolving regulatory framework and committee consensus. These concurring elements introduce potential biases and gaps in knowledge, particularly in cases where corporate strategies or confidential data are unavailable, leading to discrepancies between declared and actual technology readiness or adoption. The use of PRISMA is further complicated by the multinational nature of the project, involving actors from various jurisdictions, regulatory regimes, and market contexts, where data transparency is uneven, and technology deployment is subject to localized policies and economic constraints. These conditions create a landscape where uncertainty and the risk of contradictions in evaluations are elevated, especially where company-specific interests and national contexts drive divergent expectations of EET performance.

- Importance of Consensus in Decision-Making

Despite these uncertainties, the project has emphasized the importance of structured consensus-building among stakeholders. While recognizing that such decisions, once fixed by deliverables and deadlines, could constrain future flexibility in research, consensus is necessary to ensure continuity and comparability. In Task 2.1, two foundational decisions emerged as critical: the selection and categorization of EETs, and the adoption of a fleet-level analysis rather than a vessel-specific approach. These choices directly influence the development of the taxonomy, affecting how EETs are benchmarked, prioritized, and harmonized across the work packages.

- Fleet-Level vs. Vessel-Level Analysis

Adopting a fleet-level perspective over a vessel-specific one was based on the need to standardize and scale evaluations across vessel types, operational profiles, and company strategies. The methodology adopted in this D2.1 does not consider the compatibility of different EETs when implemented and combined on a specific ship. In general terms, many EETs do not preclude the adoption of other EETs, but their combination should be carefully considered to prevent wrong assumptions (e.g. multiple use of the same thermal energy or electric power) and this would require a vessel-specific analysis of the power load balance. While vessel-level granularity could provide detail, it is not feasible due to data limitations and the complexity of aggregating such individualized insights across the consortium. The fleet-level approach, by contrast, facilitates comparative assessment, enables clustering of EET metrics, and aligns better with regulatory frameworks and commercial strategies at scale.

- Trends in Technology, Regulation, and Global Dynamics

Looking forward, the project operates in an environment of rapidly evolving regulations and technologies, where changes in IMO Net-zero strategies, EU Fit for 55 directives, and emergent decarbonization pathways will reshape the viability and priority of EETs. This

includes zero-carbon fuels (e.g., hydrogen, ammonia), biofuels, hybrid power systems, and AI-driven optimization tools. Additionally, geopolitical disruptions including war, trade restrictions, and national energy security policies are altering shipping lanes and fuel accessibility, further affecting the global market and the technology adoption landscape.

- Role of Taxonomy in Scalability and Tracking

In this context, the EET taxonomy becomes essential, not merely as a categorization tool but as a scalable and trackable system for mapping technology readiness, stakeholder interest, and deployment feasibility. By grounding EETs in structured categories and metrics, the taxonomy enables better strategic decision-making, fosters multinational collaboration, and ensures that emerging innovations can be integrated and monitored as the project evolves.

Chapter 8 Conclusions and Next Steps

Conclusions:

Task 2.1 has successfully established a robust foundation for evaluating (EETs) within the FLEETFor55 project. A structured taxonomy was developed and validated in collaboration with project partners, encompassing 7 key categories and 68 individual EETs. This classification enables a comprehensive understanding of where and how technologies apply across vessel types and operational profiles.

The analysis integrated a multidimensional methodology combining literature review, expert consultation, and industry input via the TIN network. The result is a harmonised matrix that aligns technical readiness, operational applicability, and industry relevance. A key insight is that many technologies have cross-segment potential, while others particularly novel solutions still face data and deployment uncertainties. Furthermore, fleet-level analysis has proven critical for understanding broader impacts, synergies, and implementation feasibility.

Next Steps:

- **Technology Prioritisation:** Select high-impact EETs for deeper techno-economic evaluation in Tasks 2.2–2.5 and T3.1, based on TRL, industry demand, regulatory framework and available data.
- **Decision-Support Tool:** Begin development of a system that incorporates taxonomy structure, metrics, and fleet-level modelling.
- **Data Enrichment:** Expand the database with performance metrics (operational, maintenance, environmental, economic, social) and continue expert validation.
- **Stakeholder Engagement:** Integrate feedback from the Expert Advisory Board (EAB) and newly onboarded companies to refine assumptions.
- **Scalability and Flexibility:** Ensure taxonomy and evaluation framework remain adaptable to regulatory, geopolitical, and technological trends.

A critical conclusion of Task 2.1 is the foundational role it plays in establishing robust criteria for the evaluation of alternative EETs and the development of a structured taxonomy. This framework is essential for defining and applying relevant metrics to each technology. Given the scalability and complexity required to assess diverse companies across multiple energy dimensions and evaluation layers, Task 2.1 lays the groundwork for a comprehensive fleet-level analysis. Moreover, it ensures consistency and methodological clarity, directly supporting the taxonomy and evaluation approaches needed in WP3 and influencing the broader impact and coherence of subsequent work packages throughout the FLEETfor55 project.

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Annex A – Energy Efficiency Technology (EET)

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Hydrodynamic Efficiency Improvements	2. Hull Form Optimization (Streamlined Design for Efficiency)
Hydrodynamic Efficiency Improvements	3. Air lubrication systems (ALS)
Hydrodynamic Efficiency Improvements	4. Hull Surface Coatings & Low-Drag Paints
Hydrodynamic Efficiency Improvements	5. Bulbous Bow Optimization
Hydrodynamic Efficiency Improvements	6. Hull Openings and Skeg Shape Optimization
Hydrodynamic Efficiency Improvements	7. Trim & draft optimization
Hydrodynamic Efficiency Improvements	8. Variaton of block coefficient/lengthening (Inland)

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Operations & Digital Optimization	9. Hull Cleaning & Condition-Based Monitoring - onboard measurements
Operations & Digital Optimization	10. Hull Protection based on Ultrasound tech
Operations & Digital Optimization	11. CPP pitch optimization and propeller performance monitoring - onboard measurements
Operations & Digital Optimization	12. Weather routing systems for voyage speed/fuel optimization
Operations & Digital Optimization	13. Just-in-time (JIT) arrival strategies
Operations & Digital Optimization	14. Speed optimization (slow steaming)
Operations & Digital Optimization	15. Port Turnaround Time Reduction
Operations & Digital Optimization	16. Cargo Load Factor Optimization
Operations & Digital Optimization	17. Autopilot Upgrade and Adjustment

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Optimized Engineering Approaches	1. Onboard Carbon Capture and Storage (CCS) Systems
Optimized Engineering Approaches	18. Water-Emulsified Fuel Technology
Optimized Engineering Approaches	19. Main Engine Tuning & Optimization
Optimized Engineering Approaches	20. Variable Frequency Drive (VFD) for speed control (e.g. pumps, fans)
Optimized Engineering Approaches	21. Lightweight shipbuilding materials (composites, aluminum)
Optimized Engineering Approaches	22. Reduced Auxiliary Power Demand
Optimized Engineering Approaches	23. Steam/heat plant improvements/optimization
Optimized Engineering Approaches	24. Advanced HVAC & cooling systems

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Power Conversion, Electrification & Energy Devices	25. Heaving Oscillating Systems
Power Conversion, Electrification & Energy Devices	26. Full Electric Propulsion Concepts (e.g. dynafin, Superconducting electric motors)
Power Conversion, Electrification & Energy Devices	27. Alternative Fuelled 2-S ICEs (e.g. hydrogen, ammonia, methanol)
Power Conversion, Electrification & Energy Devices	28. Alternative Fuelled 4-S ICEs/Gensets (e.g. hydrogen, ammonia, methanol, biofuels)
Power Conversion, Electrification & Energy Devices	29. Waste heat recovery systems (WHRS)

Power Conversion, Electrification & Energy Devices	30. PEM fuel cells
Power Conversion, Electrification & Energy Devices	31. SOFC fuel cells
Power Conversion, Electrification & Energy Devices	32. Other type of fuel cells
Power Conversion, Electrification & Energy Devices	33. Energy storage systems (ESS) – lithium-ion batteries
Power Conversion, Electrification & Energy Devices	34. Energy storage systems (ESS) – redox flow batteries (RFB)
Power Conversion, Electrification & Energy Devices	35. Onshore Power Supply [OPS]
Power Conversion, Electrification & Energy Devices	36. Low-Loss Power Distribution Systems (for new builds)
Power Conversion, Electrification & Energy Devices	37. Shaft Generator PTI, PTO, PTI/PTO
Power Conversion, Electrification & Energy Devices	65. Onboard Power Systems and Power Electronics (converters, switches, solid-state transformers)
Power Conversion, Electrification & Energy Devices	66. DC Grid technologies
Power Conversion, Electrification & Energy Devices	67. Electric propulsion systems and thrusters (including Rim-driven thrusters)
Power Conversion, Electrification & Energy Devices	68. Energy Management Systems (EMS)

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Propeller & Propulsion Optimization	39. Post-swirl ESD Contra-rotating propellers (CRP)
Propeller & Propulsion Optimization	40. Pre-swirl ESD Wake Equalizing Ducts (WEDs)
Propeller & Propulsion Optimization	41. Pre-swirl ESD ESD Fins
Propeller & Propulsion Optimization	42. Manoeuvring devices (e.g. Gate rudder)
Propeller & Propulsion Optimization	43. Propeller Nozzle (e.g. Kort)
Propeller & Propulsion Optimization	44. Post-swirl ESD PBCF (Propeller Boss Cap Fins)
Propeller & Propulsion Optimization	45. Post-swirl ESD Grim Vane Wheel
Propeller & Propulsion Optimization	46. Pulling Azimuth Thrusters
Propeller & Propulsion Optimization	47. Propeller-Retrofitting Advanced propeller Blade Sections (e.g. Winglets/kappel)

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)
Renewable Energy Integration	38. Hydrofoil-Based Wave Energy Converters
Renewable Energy Integration	48. WASPs - Soft Sails
Renewable Energy Integration	49. WASPs - Flettner Rotors (Magnus Effect Rotors)
Renewable Energy Integration	50. WASPs - Rigid Wing Sails
Renewable Energy Integration	51. WASPs - Kite Propulsion Systems
Renewable Energy Integration	52. WASPs - Suction Wings (Ventifoils)
Renewable Energy Integration	53. WASPs - Turbosails
Renewable Energy Integration	54. WASPs - Dynarig (DynaRig) System
Renewable Energy Integration	55. SOLAR - Photovoltaic (PV) Panels for Ships

Categorization (TIN-TBD)	Energy Efficiency Technology (EET)

Sustainable, Climate-Neutral & Low-Emission Fuels	56. Fuel Reforming/Cracking
Sustainable, Climate-Neutral & Low-Emission Fuels	57. Methanol
Sustainable, Climate-Neutral & Low-Emission Fuels	58. Biomethane
Sustainable, Climate-Neutral & Low-Emission Fuels	59. Ammonia
Sustainable, Climate-Neutral & Low-Emission Fuels	60. Biodiesel
Sustainable, Climate-Neutral & Low-Emission Fuels	61. Synthetic Biofuels (Power-to-Liquid E-Fuels)
Sustainable, Climate-Neutral & Low-Emission Fuels	62. Hydrotreated Vegetable Oil (HVO - Renewable Diesel)
Sustainable, Climate-Neutral & Low-Emission Fuels	63. Hydrogen
Sustainable, Climate-Neutral & Low-Emission Fuels	64. Synthetic e-fuels

Annex B – Taxonomy Structure proposed for FLEETfor55

Category: Power Conversion, Electrification, and Energy Devices

Table 24. Proposed Taxonomy for the Power Conversion, Electrification, and Energy Devices category.

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	25. Heaving Oscillating Systems	EC-1.0. - [PEE]-25.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	26. Full Electric Propulsion Concepts (e.g. dynafin, Superconducting electric motors)	EC-1.0. - [PEE]-26.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	27. Alternative Fuelled 2-S ICEs (e.g. hydrogen, ammonia, methanol)	EC-1.0. - [PEE]-27.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	28. Alternative Fuelled 4-S ICEs/Gensets (e.g. hydrogen, ammonia, methanol, biofuels)	EC-1.0. - [PEE]-28.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	29. Waste heat recovery systems (WHRS)	EC-1.0. - [PEE]-29.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	30. PEM fuel cells	EC-1.0. - [PEE]-30.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	31. SOFC fuel cells	EC-1.0. - [PEE]-31.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	32. Other type of fuel cells	EC-1.0. - [PEE]-32.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	33. Energy storage systems (ESS) – lithium-ion batteries	EC-1.0. - [PEE]-33.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	34. Energy storage systems (ESS) – redox flow batteries (RFB)	EC-1.0. - [PEE]-34.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	35. Onshore Power Supply [OPS]	EC-1.0. - [PEE]-35.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	36. Low-Loss Power Distribution Systems (for new builds)	EC-1.0. - [PEE]-36.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	37. Shaft Generator PTI, PTO, PTI/PTO	EC-1.0. - [PEE]-37.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	65. Onboard Power Systems and Power Electronics (converters, switches, solid-state transformers)	EC-1.0. - [PEE]-65.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	66. DC Grid technologies	EC-1.0. - [PEE]-66.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	67. Electric propulsion systems and thrusters (including Rim-driven thrusters)	EC-1.0. - [PEE]-67.
Energy Consumers	EC-1.0.	Power Conversion, Electrification, and Energy Devices	EC-1.0. - [PEE]	68. Energy Management Systems (EMS)	EC-1.0. - [PEE]-68.

Category: Sustainable, Climate-Neutral and Low Emission Fuels

Table 25. Proposed Taxonomy for the Sustainable, Climate-Neutral and Low Emission Fuels category

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	56. Fuel Reforming/Cracking	EC-1.0. - [SCE]-56.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	57. Methanol	EC-1.0. - [SCE]-57.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	58. Biomethane	EC-1.0. - [SCE]-58.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	59. Ammonia	EC-1.0. - [SCE]-59.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	60. Biodiesel	EC-1.0. - [SCE]-60.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	61. Synthetic Biofuels (Power-to-Liquid E-Fuels)	EC-1.0. - [SCE]-61.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	62. Hydrotreated Vegetable Oil (HVO - Renewable Diesel)	EC-1.0. - [SCE]-62.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	63. Hydrogen	EC-1.0. - [SCE]-63.
Energy Consumers	EC-1.0.	Sustainable, Climate-Neutral and Low Emission Fuels	EC-1.0. - [SCE]	64. Synthetic e-fuels	EC-1.0. - [SCE]-64.

Category: Renewable Energy Integration

Table 26. Proposed Taxonomy for the Renewable Energy Integration category

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	38. Hydrofoil-Based Wave Energy Converters	EH-2.0. - [REI]-38.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	48. WASPs - Soft Sails	EH-2.0. - [REI]-48.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	49. WASPs - Flettner Rotors (Magnus Effect Rotors)	EH-2.0. - [REI]-49.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	50. WASPs - Rigid Wing Sails	EH-2.0. - [REI]-50.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	51. WASPs - Kite Propulsion Systems	EH-2.0. - [REI]-51.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	52. WASPs - Suction Wings (Ventifoils)	EH-2.0. - [REI]-52.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	53. WASPs - Turbosails	EH-2.0. - [REI]-53.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	54. WASPs - Dynarig (DynaRig) System	EH-2.0. - [REI]-54.
Energy Harvesting	EH-2.0.	Renewable Energy Integration	EH-2.0. - [REI]	55. SOLAR - Photovoltaic (PV) Panels for Ships	EH-2.0. - [REI]-55.

Category: Propeller and Propulsion Optimization

Table 27. Proposed Taxonomy for the Propeller and Propulsion Optimization category.

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	39. Post-swirl ESD Contra-rotating propellers (CRP)	PH-3.0 - [PPO]-39.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	40. Pre-swirl ESD Wake Equalizing Ducts (WEDs)	PH-3.0 - [PPO]-40.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	41. Pre-swirl ESD ESD Fins	PH-3.0 - [PPO]-41.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	42. Manoeuvring devices (e.g. Gate rudder)	PH-3.0 - [PPO]-42.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	43. Propeller Nozzle (e.g. Kort)	PH-3.0 - [PPO]-43.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	44. Post-swirl ESD PBCF (Propeller Boss Cap Fins)	PH-3.0 - [PPO]-44.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	45. Post-swirl ESD Grim Vane Wheel	PH-3.0 - [PPO]-45.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	46. Pulling Azimuth Thrusters	PH-3.0 - [PPO]-46.
Propulsion & Hull	PH-3.0.	Propeller and Propulsion Optimisation	PH-3.0 - [PPO]	47. Propeller-Retrofitting Advanced propeller Blade Sections (e.g. Winglets/kappel)	PH-3.0 - [PPO]-47.

Category: Hydrodynamics Efficiency Improvements

Table 28.Proposed Taxonomy for the Hydrodynamics Efficiency Improvements category.

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	2. Hull Form Optimization (Streamlined Design for Efficiency)	PH-3.0 - [HEI]-2.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	3. Air lubrication systems (ALS)	PH-3.0 - [HEI]-3.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	4. Hull Surface Coatings & Low-Drag Paints	PH-3.0 - [HEI]-4.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	5. Bulbous Bow Optimization	PH-3.0 - [HEI]-5.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	6. Hull Openings and Skeg Shape Optimization	PH-3.0 - [HEI]-6.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	7. Trim & draft optimization	PH-3.0 - [HEI]-7.
Propulsion & Hull	PH-3.0.	Hydrodynamics Efficiency Improvements	PH-3.0 - [HEI]	8. Variaton of block coefficient/lengthening (Inland)	PH-3.0 - [HEI]-8.

Category: Optimized Engineering Approaches

Table 29.Proposed Taxonomy for the Optimized Engineering Approaches category.

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	1. Onboard Carbon Capture and Storage (CCS) Systems	MP-4.0 - [OEA]-1.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	18. Water-Emulsified Fuel Technology	MP-4.0 - [OEA]-18.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	19. Main Engine Tuning & Optimization	MP-4.0 - [OEA]-19.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	20. Variable Frequency Drive (VFD) for speed control (e.g. pumps, fans)	MP-4.0 - [OEA]-20.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	21. Lightweight shipbuilding materials (composites, aluminum)	MP-4.0 - [OEA]-21.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	22. Reduced Auxiliary Power Demand	MP-4.0 - [OEA]-22.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	23. Steam/heat plant improvements/optimization	MP-4.0 - [OEA]-23.
Machinery & Power Systems	MP-4.0.	Optimised Engineering Approaches	MP-4.0 - [OEA]	24. Advanced HVAC & cooling systems	MP-4.0 - [OEA]-24.

Category: Operational and Digital Optimization

Table 30. Proposed Taxonomy for the Operational and Digital Optimization category.

1st Category	Taxonomy Code	2nd Subcategory	Taxonomy Code	3rd Subcategory	Taxonomy Code
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	9. Hull Cleaning & Condition-Based Monitoring - onboard measurements	OO-5.0. - [ODO]-9.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	10. Hull Protection based on Ultrasound tech	OO-5.0. - [ODO]-10.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	11. CPP pitch optimization and propeller performance monitoring - onboard measurements	OO-5.0. - [ODO]-11.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	12. Weather routing systems for voyage speed/fuel optimization	OO-5.0. - [ODO]-12.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	13. Just-in-time (JIT) arrival strategies	OO-5.0. - [ODO]-13.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	14. Speed optimization (slow steaming)	OO-5.0. - [ODO]-14.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	15. Port Turnaround Time Reduction	OO-5.0. - [ODO]-15.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	16. Cargo Load Factor Optimization	OO-5.0. - [ODO]-16.
Operational Optimization	OO-5.0.	Operational and Digital Optimisation	OO-5.0. - [ODO]	17. Autopilot Upgrade and Adjustment	OO-5.0. - [ODO]-17.