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Global and regional regulatory framework for the decarbonization of shipping and ports: Best Practices from U.S ports

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Abstract

This dissertation examines the possible pathways, existing tools, future scenarios as well as barriers existing in the journey of the shipping sector to achieve what International Maritime Organization (IMO) has set as targets by 2050 and examines the role of ports in reaching the goals that have been set from the various regulatory bodies. Through comprehensive review of current literature, case studies and reports, we examine the various existing measures that have been planned for the decarbonization of ports and their role to a more sustainable environment succeeding the regulatory targets set but also the need for sustainable growth of the ports for the community. Additionally, this thesis examines specifically the readiness of U.S ports providing a brief discussion on the various initiatives that have been already or are under discussion for three main ports of U.S. This thesis provides also the potential benefit and challenges that are arising from the complexity and different features of the Ports.

Key Words: Decarbonization, Sustainable Growth, Regulatory Targets, Ports Decarbonization, Readiness of U.S Ports.

Περίληψη

Αυτή η εργασία εξετάζει τους τρόπους , τα υπάρχοντα μέσα ,τα μελλοντικά σενάρια καθώς και τα εμπόδια που προκύπτουν από την προσπάθεια της Ναυτιλίας να επιτύχει την επίτευξη των στόχων του Διεθνούς Ναυτιλιακού Οργανισμού (IMO) για την απανθρακοποίηση της ναυτιλίας έως το 2050. Επιπλέον γίνεται αναφορά στο ρόλο των λιμένων και στη επίτευξη των στόχων που έχουν τεθεί από διάφορους ρυθμιστικούς φορείς. Μέσω μιας ολοκληρωμένης ανασκόπησης της τρέχουσας βιβλιογραφίας, μελετών περιπτώσεων και αναφορών, εξετάζουμε τα διάφορα υπάρχοντα μέτρα που έχουν προγραμματιστεί για την απανθρακοποίηση των λιμένων και τον ρόλο τους σε ένα πιο βιώσιμο περιβάλλον, επιτυγχάνοντας το κανονιστικό πλαίσιο που έχει τεθεί, αλλά και την ανάγκη για βιώσιμη ανάπτυξη των λιμένων για την κοινότητα. Επιπλέον, αυτή η εργασία εξετάζει συγκεκριμένα την ετοιμότητα των λιμένων των ΗΠΑ, κάνοντας αναφορά στις διάφορες πρωτοβουλίες που έχουν ήδη ληφθεί ή βρίσκονται υπό συζήτηση για τρεις κύριους λιμένες των ΗΠΑ. Τέλος, η εργασία αυτή αναλύει τα πιθανά οφέλη και τις προκλήσεις που προκύπτουν από την πολυπλοκότητα και τα διαφορετικά χαρακτηριστικά των λιμένων.

Λέξεις Κλειδιά : Απανθρακοποίηση, Βιώσιμη ανάπτυξη, Ρυθμιστικό πλαίσιο, Απανθρακοποιήση λιμένων, Ετοιμότητα των Λιμένων των Η.Π.Α

Contents

1. Introduction

The shipping industry plays a major role in the international trade (~80 %, ~90% of the global trade is transferred through shipping) making the sector vital to the world economy. As shipping is considered one of the largest GHG emitting sectors, therefore there is a strict set of environmental regulations around NOx, SOx, C02 emissions that are causing major technological alterations in the industry. The role of stakeholders such as policymakers as well as investors is crucial to unlock concrete actions. Policymakers should create a policy framework that permits the achievement of the IMO GHG strategy. Shipowners are being driven from the regulations and stakeholders lead initiatives to alter their operational practices, install onboard air pollution control equipment, e.g. Sox scrubbers and selective major saving technology as well as differentiate their fuel portfolios to include low-sulfur and low-carbon alternative fuels. In order to accomplish IMO's goal of zero-emission shipping by 2050, it is expected from shipowners to trace, examine and include the use of alternative fuels, technologies and provide solutions that will assist in the ultimate goal of minimizing energy consumption. Ports are also having a major role as a key stakeholder in the initiatives for sustainability and reducing GHG emissions. Ports and terminals are critical points in the maritime transportation network. They constitute a frontier for pollution with multiple anthropogenic inputs since they consume a lot of fossil fuels and are unavoidable sources of contemplated maritime transport emissions. As ports receive major pressure in order to support the environmental credibility, they address climate change issues, they support and enhance the corporate social responsibility and move forward with various actions and initiatives that are related in a portside, landside and ship interface level.

2. Trends in Environment Regulations for International Shipping

2.1. Initial IMO GHG strategy

During 2018, IMO adopted its initial GHG strategy, emphasizing the goal of reducing the yearly emissions that arise from the international shipping by over half by 2050 compared to 2008 levels with final intentions to eliminate the GHG emissions from shipping within this century. The strategy has three basic aims:

- Minimize the carbon intensity of ships with the operation of further phases of EEDI for new vessels. The percentage of improvement for each phase is being defined from vessel's type.
- Minimize the carbon intensity of global shipping, attempting to shrink C02 emissions per transport work by at least 40% by 2030 in comparison to 2008 levels, having as a target of 70% reduction by 2050.
- Reduce GHG emissions from global shipping in the shortest time possible in order to accomplish a reduction of a minimum 50 % in total annual GHG emissions in 2050 compared to 2008 and try to achieve the phase-by-phase reduction as one of the C02 emission reductions road in accordance with the Paris Agreement Temperature targets.

2.2. 2023 IMO GHG strategy

2023 IMO'S Strategy on Reduction of GHG emissions has been decided through the 80th session of the MEPC in July 2023. The revised Strategy had as a goal to strengthen the ways to achieve net zero GHG emissions from global shipping by 2050. The main points received from the IMO Strategy are:

- Approve of zero (or near -zero) GHG emission technologies, fuels and/or energy resources to represent at least 5%, striving for 10% of the energy utilized by international shipping by 2030.

- IMO has the intention of achieving that with regulations for the use of onshore power supply, environmentally not-harmful biofuels, onboard carbon capture and storage (CCS), e-fuels and blue fuels which are expected to be finalized.
- Increasing the ultimate target to achieve net-zero emissions by or nearby i.e. close to 2050. This is marking a major increase from the original IMO GHG strategy, which pursued a 50 % reduction in GHG emissions by 2050.

2.3. EU FIT FOR 55

The European Commission (EC) recently said that it will modify the EU Green Deal, also referred to as the European climate law, in order to achieve carbon neutrality by 2050. When it adopted the "Fit for 55" package with 13 measures in July 2021, the European Commission (EC) promised to cut greenhouse gas emissions by at least 55% (relative to 1990 levels) by 2030. The following four proposals (legislations) directly affect the maritime industry: (Jeong, 2022)

EU Emission Trading System (EU-ETS)

Shipping companies will be required to pay credits for 50% of emissions for voyages between EU and non-EU ports. While an impending collapse is at present bringing down shipping prices, they are unlikely to revert to pre-pandemic levels in the long run because the additional costs must eventually be compensated for.

The ETS is crucial to EU climate policy, accounting for 40% of emissions from enterprises in industries that are having high energy utilization. It aims to cut GHG emissions by 61% by 2030 in comparison to 2005 levels. The EU's anticipated Carbon Border Adjustment Mechanism (CBAM), which is set to be set and work in full in 2026, will levy a tax on trade in goods in specific sectors when emissions that occur from production have not been equally under taxation by the exporter's country. This is intended to block goods coming in from countries that do not consider climate policies as important and undermining the EU's efforts to reduce greenhouse gas emissions. It will also be essential in the phase-out of free permits for EU producers. (Jeong, 2022).

FuelEU Maritime

The FuelEU Maritime scheme, which was filed in July 2021 as part of the endeavor to attain "Fit for 55," suggests an active code of action to promote decarbonization in the maritime industry. This proposal's main goal is to encourage the sustainable use of marine fuels by removing obstacles in the market and actively creating greener technology.

Regardless of flag state, this proposal targets any ships that call in Europe that weigh five thousand GT or more. The objective of carbon reduction is to establish the standard value for the average GHG generated on board ships in 2020 and to decrease it.

It should be emphasized, however, that the FuelEU Maritime reduction objective accounts for both the life cycle greenhouse gas emissions (Well-to-Wake, WtW) of different fuels and corresponding engine technology, in addition to the onboard emissions (Tank-to-Wake, TtW).

Energy Taxation Directive (ETD)

This plan primarily encourages the usage of alternative fuels for ships in the EU by outlining the new tax structure and tax exemption benefits for marine fuels used and supplied inside the European Economic Area (EEA) starting in 2023. The main goal of a recent change was to minimize the tax rate on cleaner fuels utilized in European passenger ships, fishing vessels, and cargo ships. (Jeong, 2022)

Alternative Fuel Infrastructure Directive (AFID)

The Directive aims to guarantee LNG bunkering facilities by 2025 and provide the port with electricity that can accommodate over 90% of container and passenger ships in port as one of the initiatives to support FuelEU Maritime. It was suggested to get the spaces ready for the device's installation. (Jeong, 2022)

2.4. CARB REGULATIONS

Maritime industry is also being impacted from some aspects of CARB Regulations. The California Air Resources Board (CARB) regulations are a set of rules and standards aimed at reducing air pollution and improving air quality in California. CARB is responsible for monitoring and regulating air emissions from various sources, including vehicles, industrial facilities, and other pollution sources. The California Air Resources Board (CARB) has implemented several regulations that significantly impact the shipping industry. The **Ocean-Going Vessels at Berth Regulation**, specifically, is one of the major ways that the California Air Resources Board (CARB) laws are affecting the shipping industry.

The regulation has as foundation the goals set by the 2007 adoption of the At-Berth Regulation. Since 2014, the ordinance has reduced hazardous emissions from over 13,000 vessel trips by 80%. The amended rule includes new vessel types that, when they run auxiliary engines or, in the case of most tanker boats, auxiliary boilers while docked, must limit emissions. The berth period of a vessel might be anything from a few hours to several days, during which time these auxiliary engines supply the electricity and other on-board functions.

Cruise ships, "reefers" (vessels transporting refrigerated cargo), and container ships are among the ships incorporated in the current regulation. The amended rule now includes auto carriers and tankers, two types of merchant vessels that account for 56% of all fine particulate pollution produced while berthed in ports in California. When the revised rule is completely put into effect, it will reduce pollution from an estimated 2,300 more vessel visits annually by 90% and lower the risk of cancer in communities close to the Ports of Los Angeles, Long Beach, and Richmond by 55%.

The modified regulation will take effect in 2023 and replace the earlier one, which applies to container, reefer, and cruise vessels. The current regulation will remain in effect until 2022. Beginning in 2019, auto carriers will have to comply in 2025, on the contradictory tankers in Northern California have until 2027. (Board, 2020)

If there is more time required from ship owners, terminal and port operators because of lack of appropriate time they are able to petition the Board in order to use other ways for completing the emissions reductions in port-adjacent communities.

In order to comply with the regulation, ships or terminals that are not capable to connect a vessel to an emissions control technology during a visit (due to equipment failure, port congestion, etc.) may submit a request for a Terminal or Vessel Incident Event. Each regulated terminal operator and vessel fleet is only granted a certain number of these events annually.

Another regulation that emits from the California Air Resources Board (CARB) is the **Commercial Harbor Craft (VHC) Regulation** by the California Air Resources Board (CARB) and has a goal to reduce emissions from diesel engines on commercial harbor craft operating in California waters. The rule covers a wide range of harbor craft, such as barges, dredges, crew and supply boats, tugboats, ferries, and fishing vessels. It considers mostly the new and old boats that are using inland and coastal waterways in California.

The legislation requires cleaner engines and technology to reduce emissions. This includes updating to newer, cleaner engines and applying cutting-edge emission control technologies. (Board, 2022).

Recent modifications to the CHC Regulation, effective December 30, 2022, broaden its application to new vessel types and impose tighter emission standards. These changes are anticipated to considerably cut emissions, with an 89% decrease in diesel particulate matter and a 52% decrease in nitrogen oxides by 2035. (Board, 2022). Vessel operators must comply with the new regulations within specific time limit, with some restrictions beginning as early as January 1, 2023.

Another element of the CARB Regulations is the Truck and Bus Regulation which was established in 2008 and has as a goal to minimize emissions of greenhouse gases and diesel exhaust particulate matter, which has negative impacts to the human health and environment. The regulation aims to all diesel trucks and busses that operate in the state and are having a Gross Vehicle Weight Rating (GVWR) greater than 14,000 pounds. This regulation does not affect shipping industry directly but has a key impact on the shipping logistics by requesting cleaner engines for the vehicles that are transferring goods from and to the port. (Critchfield, 2019)

2.5. CLEAN SHIPPING ACT 2023

The Clean Shipping Act of 2023 seeks to transform objectives into action as regulators become more aware of the demand for sustainability-related action. This act has been presented as piece of legislation with high expectations that aims to significantly decrease the carbon intensity of fuels that are being utilized by marine vessels over the next few years, with the goal of completely decarbonizing maritime commerce by 2040. (Robinson, 2023)

The foundation for the Clean Shipping Act and the first of this kind federal law was the Clean Air Act (CAA) that has as a purpose to track air pollution and put under regulation the air emissions occurred from static and mobile sources/elements. The first version was implemented during 1963 with a revised version established in 1970. Latest and most update with the significant changes document presented in 1990. The U.S Environmental Protection Agency (EPA) was authorized from CAA to implement National Ambient Quality Standards (NAAQS) that will support the safeguarding of public health and environment. The revised version that came in 1990 addressed issues such as acid rain, urban air quality, toxic air pollutants, and motor vehicle emissions and fuels.

The Clean Shipping Act has been essentially created based on the foundation of CAA in order to address the issues arising from the air pollution that comes from shipping industry. (Robinson, 2023)

Guidelines and regulations included in the act have as main goal to minimize the carbon intensity of fuels used from container ships. The standards are ongoing subject to progress, and they are aiming ultimate goals to be succeeded by 2040.

The main specifications of the Clean Shipping Act 2023 are defined as:

- During the period of 2027 -2029 the carbon intensity for the fuel used from ships should be at least
- 20% less than the decided carbon intensity baseline.
- Following from 2030 to 2034, 45% less than the baseline is the goal that has been set.
- From 2035 to 2039, desired reduction should be 80% less than the baseline.
- Finally, from the year 2040 and after ships should have succeeded the 100% less than the baseline.

The Act recognizes the intensive work from the internation community and IMO and has the ability to engage with the standards set by IMO if they are set as the same or more competitive than the U.S standards.

3. Regulatory Timeframe

Primarily, International Maritime Organization (IMO) is leading the regulatory framework for the decarbonization of shipping with EU also having an active role. Below regulatory timeline reflects the commitment to reducing GHG emissions and it is promoting sustainable practices in the maritime industry. The strategies involve a combination of technical innovations, alternative fuels, and regulatory measures to achieve the highly ambitious targets. (List, 2024)

3.1. Early Years (2011–2023)

Year		Regulatory Body	Regulation / Goal
2011		IMO	➢ IMO introduces initial mandatory, technical and operational regulations to increase energy efficiency in ships. Ranks set under the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships to be to be enhanced every five years. ➢ Controversial decision taken by voting, decision taken by vote, including five countries with objection (China, Brazil, Saudi Arabia etc.)
2013		IMO	➢ Energy efficiency regulations. EEDI and SEEMP are being implemented, and they are applicable to all ships that exceed 400gt.
2015		IMO / EU	➢ Phase 1 of the IMO's EEDI initiative to reduce carbon intensity of new ships by 10% has begun. ➢ EU regulations require monitoring, reporting, and verification (MRV) of fuel consumption for ships over 5,000 gt calling at European ports. First reporting period to begin January 1, 2018.
2016		IMO	➢ The IMO has agreed to create a database for measuring greenhouse gas (GHG) emissions from ship fuel oil usage starting in 2019. Oil consumption reported by flag states yearly to the IMO database.

3.2. Intermediate Years (2018 – 2023)

2018		IMO	➢ April: The IMO establishes its initial targets for reducing greenhouse gas emissions. The 'Initial IMO Strategy on the Reduction of Greenhouse Gas Emissions from Ships' aims to decrease carbon intensity by at least 40% by 2030 (with a goal of 70% by 2050) and total annual GHG emissions from international shipping by at least 50% by 2050 compared to 2008, with the goal of phasing them out as soon as possible. The 2050 'level of ambition', i.e. aim, will be harmonized with the Paris Agreement temperature goals. ➢ In June, the Marine Environmental Protection Committee- MEPC postponed discussions on carbon taxes and other measures to reduce shipping emissions until the November discussion. The IMO establishes a three-phase plan timeframe for developing medium- and long-term greenhouse gas mitigation strategies. Phase 1 (collection and consideration of various measures) will take place from Spring 2021 to Spring 2022; Phase 2 (assessment and selection of measures for further growth) will take place from Spring 2022 to Spring 2023, alongside ongoing work to revise the initial GHG strategy; and Phase 3 (progress, finalization, and adoption of any agreed-upon long-term measures) has no timeframe. ➢ In October, the IMO agreed on a decarbonization regulation schedule. Short-term decarbonization actions will be concluded and settled between 2018 and 2023; mid-term measures between 2023 and 2030; and long-term measures after 2030.
2021		IMO / EU	➢ In June, the IMO approved the first set of "short-term measures" stated in the 2018 regulation framework, establishing technical and operational efficiency standards for ships starting in 2023. The Energy Efficiency Existing Ship Index (EEXI), yearly operating Carbon Intensity Indicator (CII), and CII grade are intended to reduce annual CO2 intensity by 2% between 2023 and 2026. Further CO2 intensity reduction objectives for 2027-2030 have been pushed to 2026. There is no implementation mechanism for ships with low CII ratings.

			➢ In July, the EU27 launched the Fit for 55 strategies, which aims to reduce GHG emissions by 55% by 2030, including shipping. Legislative amendments contain FuelEU Maritime laws that limit the amount of well-to-wake GHG energy used on ships. Beginning in 2025, global shipping will be involved in the EU's carbon pricing market through the Emissions pricing System (ETS). ➢ October: The Clydebank Declaration to construct green shipping routes is signed at COP26 in Glasgow. In total, 24 countries have pledged to support zero-emission shipping routes for at least six green corridors "by the middle of this decade". ➢ In November, the IMO postponed discussions on implementing market-based policies like carbon taxes, cap-and-trade, and 'feebate' systems until six months later. The Marine Environment Protection Committee agrees that increased GHG-decrease objectives (i.e. higher targets) will be contained in the new strategy, which will be signed off in July 2023, despite the conflict on what they will be. EEDI phase 2 is now in effect, resulting in up to a 20% decrease in carbon intensity for new ships.
2022		IMO	➢ EEDI phase 3 is now implemented for specific ship types, with newbuild large containerships reducing their carbon intensity by up to 50%. ➢ In March, the Intersessional Working Group on Reducing Greenhouse Gas Emissions from Ships establish a December closing date for completing draft lifecycle GHG and carbon-intensity recommendations for marine fuels. ➢ April: Flag administrations or recognized organizations to report relevant EEDI values to IMO. ➢ May: The IMO's Intersessional Working Group on Greenhouse Gases examines six market-based solutions to close the gap between low-cost fossil fuels and zero-emissions fuels, including carbon tax, cap-and-trade, and 'feebate' suggestions. ➢ In June, IMO representatives rejected the shipping industry's market-based proposal to launch a $5 billion research and development fund through a $2/tonne carbon fee on marine fuels, instead requesting new proposals. Correspondence group on marine fuel lifecycle analysis (i.e., well-to-wake) formed to develop guidelines on a well-to-wake basis and gather more detail about possible "mid-term measures" (i.e., technical and pricing

			policies such as a carbon tax/levy, emissions trading system, and an incentive scheme for zero-emission ships). Enforcement is scheduled for late 2023 and 2024 (phase II of the work plan). Adopts 12 criteria for short-term solutions, including the Energy Efficiency Existing Ship Index (EEXI), enhanced Ship Energy Efficiency Management Plan (SEEMP), and Carbon Intensity Indicator (CII) rating. The recommendations define how to calculate the EEXI and the improved SEEMP. ➢ October: The International Chamber of Shipping offers an additional industry-supported economic measure, the International Maritime Sustainability Funding and Reward (IMSF&R) mechanism, paired with a flat-rate involvement scheme, ie 'fund-and-reward' program. ➢ November: Short-term EEXI and CII technical and operational measures agreed upon in 2021 go into effect, prompting significant industry complaints that the low threshold does little to cut overall carbon emissions and alters trade patterns. The IMO allows additional reporting of ship carbon intensity performance values and proposes including cargo-related data to increase accuracy. The Marine Environment Protection Committee conference ended with no agreement on stronger GHG emission limits, opposition to establishing IMO-related green corridors, and deferred discussion of carbon capture and storage.
2023		IMO / EU	➢ In January, all ships must have a validated SEEMP on board to document how they aim to meet CII targets. ➢ In March, the IMO intersessional working group approved a draft statement outlining a revised decarbonization strategy, but no additional targets were specified. ➢ In April, the EU parliament approved the inclusion of international shipping into its ETS, establishing a carbon price for the industry for the first time. ➢ In May, the EU parliament approved the world's first green shipping fuel regulation. According to FuelEU Maritime objectives, at least 2% of marine fuels must be e-fuels, such as green ammonia created from renewable electricity, by 2034 at the latest. The regulation will be updated in 2028 to apply to all intra-EU voyages and 50% of overseas voyages. Includes a "multiplier of 2" premium for utilizing green e-fuels until 2035, as well as 2%

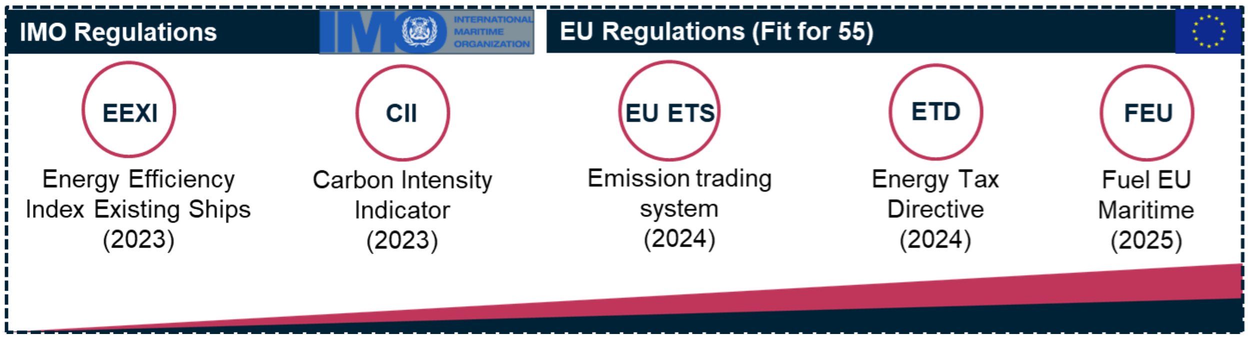
			reductions in GHG energy intensity beginning in 2025 and 6% by 2030. The figure will climb to 14.5% from 2035, 31% from 2040, 62% from 2045, and 80% by 2050. ➢ In July, the IMO approved a new GHG policy aimed at reducing emissions by 20% by 2030, 70% by 2040, and reaching net-zero by or around 2050. The targets are all based on a 2008 baseline and include ‘striving for' levels of ambition, with 30% by 2030 and 80% by 2040. Member states agree to set a new objective of 5% zero and near-zero emission fuels and technologies by 2030, with a goal of 10%. Mid-term economic and technological measures will be implemented in 2025. The IMO's new targets are on a complete lifecycle basis, often known as well-to-wake.

3.3. Present and Future (2024- 2050)

2024		IMO / EU	➢ The EU27 ETS covers shipping-related CO_2 emissions from 50% of international travel and 100% of travels among European ports. Ships will be accountable for 40% of their 2024 emissions in 2025, 70% in 2026, and 100% (only CO_2) in 2027. Based on an average CO_2 price of €90/tonne, the European Innovation Fund will receive roughly 600 million emission allowances (EUAs) until 2030 to support low-carbon technology. This is expected to generate €54 billion by 2030. 20 million EUAs, or €1.8 billion, are estimated to be put into in the maritime industry by 2030. ➢ IMO: An initial report on the thorough effect assessment of potential economic actions will be provided before MEPC 81 on March 18–22. ➢ IMO: On March 1st, the CII rankings for international ships were revealed. Ships are rated on a scale of A to E based on CO_2 grams per cargo-carrying capacity and nautical mile.
2025		IMO / EU	➢ IMO to approve and adopt mid-term measures. ➢ The FuelEU Maritime GHG intensity- reduction objectives in marine fuels start with 2% focus up until 2030. ➢ In the September of 2025 the preliminary ETS payments generated by shipping companies.

2026		IMO / EU	➢ All CO2 emissions, along with methane and nitrous oxide emissions, are contained in the EU27 ETS at 100%. ➢ IMO will complete evaluating the CII and EEXI short-term measures.
2027		IMO / EU	➢ Mid-term IMO measures are set to be implemented. The operation of a global marine fuel standard and a greenhouse gas price system launches. ➢ EU to decide whether to incorporate greenhouse gas emissions from general cargo ships between 400 and 5,000 gt and offshore ships 5,000 gt and above in its laws.
2028		IMO	➢ For the first time since 2023, the IMO will take into consideration further adjustments to its plan to decrease greenhouse gas emissions.
2030		IMO/EU	➢ The IMO set a 20% emission reduction target in July 2023 with the goal of achieving 30 % ➢ The new IMO target calls for a 40% decrease in carbon intensity in addition to a 5% uptake of fuels, energy sources, and/or technologies with zero or nearly zero GHG emissions, with a goal of 10%. ➢ FuelEU Martime: A five-year target of 6% GHG energy reduction has been established.
2034		EU	➢ FuelEU Maritime regulations delegate 2% of marine fuels to be e-fuels derived from renewable electricity.
2035		EU	➢ FuelEU Maritime has set a five-year aim of 14.5% GHG intensity energy reduction.
2040		IMO/EU	➢ FuelEU Maritime has set a five-year aim of 31% GHG energy reduction. ➢ IMO: 70% emission reduction target with 80% desired
2045		EU	➢ FuelEU Maritime: a six-percent GHG energy reduction goal over the next five years.
2050		IMO/EU	➢ FuelEU Maritime: a five-year, 80% reduction in GHG energy intensity. ➢ IMO's goal of having net-zero emissions by 2050 or around.

4. Regulatory Technical and Operational Measures



4.1. Initial technical regulations

Ship Energy Efficiency Management Plan (SEEMP)

For both new and old ships, the Ship Energy Efficiency Management Plan (SEEMP) is a management strategy that raises fuel efficiency through operational statements. For ships that are in service SEEMP is a requirement. The enhancements provided by SEEMP includes a faster vessel, more frequent cleaning of the hull or propellers, or by establishing different route choice to reach out a destination. SEEMP is specific and unique for each vessel, due to factors such as cargo, routes and dry-docking timeline. (Mallouppas and Yfantis, 2021)

Energy Efficiency Design Index (EEDI)

MARPOL was expanded to include the Energy Efficiency Design Index (EEDI) in 2001.The EEDI applies to all new vessels, and it can be described as a management tool for ship owners and operators that has a consultation role and provides potential impacts in case of any management changes. To this view through EEDI's technical efficiency improvements we have reduce of CO2 emissions. (Mallouppas and Yfantis, 2021)

Energy Efficiency Operational Index (EEOI)

The Energy Efficiency Operational Index (EEOI) has been proposed by the IMO on a voluntary basis and has a goal the measure of efficiency for existing ships. The definition of EEOI is as the ratio of mass of Co2 emitted per unit of transport work. The index is the sum up of fuel consumed at sea and port, of the particular timeframe that refers to, by the main and auxiliary engines, including boilers and incinerators. (Mallouppas and Yfantis, 2021).

4.2. Short-Term Measures (2018–2023)

The IMO developed two short measures the Energy Efficiency Existing Ship Index (EEXI) and the annual operational carbon intensity indicator (CII) and CII rating which came into force as mandatory from 1st of January of 2023.

Energy Efficiency Existing Ship Index (EEXI)

The Energy Efficiency Existing Ship Index (EEXI) applies to all vessels above 400 gross tonnage (GT) and is included in IMO's wider strategy to cut GHG emissions by at least 40% by 2030 compared to 2008 levels. EEXI is similar to EEDI that was mentioned before with the difference that EEDI applies to all new vessels built on or after January 1st, 2013, while EEXI applies to the existing fleet. The preparation of the EEXI technical file is based on data exported from several vessel's documents such as capacity plan/lightweight certificate, the trim and stability booklet, sea trials reports, NOx technical files etc. (Mallouppas and Yfantis, 2021)

EEXI does not have a particular/standard figure for all vessels, but it is defined as "required EEXI" that depends on ship type, capacity and engine. The "required EEXI" as a figure defines the minimum standard for each vessel type. Each specific vessels is credited a calculated "attained EEXI" which the figure of this needs to be less than or equal to the required EEXI in order to comply with the regulations.

EEXI refers to vessel's expected carbon emissions, reflected per cargo ton and mile taking into consideration elements such as engine power, fuel oil consumption and cargo capacity. While for a ship to be compliant with EEXI regulation does not require technical alterations to the ship itself, there is high possibility to be required in order for many vessels to achieve the minimum required EEXI rating of "C" or above. While EEXI compliance does not necessarily require technical modifications to a ship, in practice this is likely to be required for many vessels in order to achieve the minimum required EEXI rating of "C" or above.

Carbon Intensity Index (CII)

Carbon Intensity Index (CII) by using ratings from A to E it provides ratings that reflect the actual energy efficiency in grams of CO2 produced per cargo-carrying capacity and nautical mile. The rating framework tends to become significantly strict over time. In cases of vessels receiving repeatedly three D ratings or one E owners have the obligation to provide a plan with corrective actions to be followed within the next calendar year. The owner of the vessel is the one who sets the baseline for technical efficiency. Nevertheless, other parties such as operators, ports etc. affect directly a vessel's CII rating. (Center, 2022)

Is common that operators are usually conclude to decisions regarding speed instructions, trade implementation which are affecting efficiency. Also, instructions and decisions from ports and terminals are able to lead to inactive periods, causing needlessly overdue port stays which eventually leads to speed increases in order to cover the gap created from the delays. Cargo owners are also another party that can affect CII ratings, and this is the case when carrying specific cargo or demands calls on testing ports therefore affects vessel's utilization. Owners are responsible to cooperate with all the above-mentioned parties and ensure smooth operations in order to avoid being penalized.

4.3. Medium- (2023–2030) and Long-Term Measures (Beyond 2030)

Medium and long- term measures are the next set of measures that will further develop what already exists with the short- term measures. The medium and long-term measures will take under consideration the application of market-based-mechanisms and the establishment of further suggestions and projects that will lead to the final goal of reduction of emissions.

Market-Based Measures

MBMs reflect a fee on GHG emissions and the main goals they are serving are two:

- ✓ To provide an economic centric motivation to the maritime industry to minimize the fuel consumption by financing in new technologies and more fuel – efficient ships which will be operated in a more efficient -manner.
- ✓ To be able to be used in other industries as well that have increased gas emissions.

MBMs are relevant to both the short- and long-term candidate measures required to meet the IMO targets since they have the ability to bring changes equally at an operational and technological level.

Long-term or technological measures mostly include the use of low carbon or alternative fuels like biofuels, ammonia, and hydrogen, along with energy recuperation devices (e.g., exhaust heat recovery systems) and wind-assisted propulsion.

The **Goal-Based Marine Fuel Standard** is another suggested mid-term measure and is anticipated to be mandatory in 2025. IMO is preparing to approve the alterations during the Marine Environment Protection Committee (MEPC) session in April 2025, with an estimation of enforcing this measure formally in October 2025. (IMO, 2024).

The main goal of this measure is to minimize the carbon intensity that is being produced by the consumption of fuels in ships. In that way a phased reduction of the GHG intensity of marine fuels can be accelerated. This standard is a section of a wider regulatory framework, having also the potential to be included in the MARPOL Annex VI as a new chapter. (Prevljak, 2024). This framework will be enhanced also with economic mechanisms for the transition to low – and zero-carbon fuels.

The goals for reductions will be implemented in levels, permitting the industry steadily to enforce the new requirements. This steadily implementation will secure that technological improvements and infrastructure development can support the regulatory changes.

Along with the technical measure of the global – based marine fuel standard it is likely an economic mechanism(s) to incentivize the transition to net-zero. (IMO, IMO agrees possible outline for maritime "net-zero framework, 2024). This measure is part of the IMO's broader efforts to achieve its long-term decarbonization goals and support the global transition to sustainable shipping practices.

Wind-Assisted Propulsion Systems (WAPS) are an illustration of a technology that can assist vessels to save fuel and decrease emissions by adjusting the energy efficiency of the vessel. It is mostly considered as a long-term measure. Conditional on environmental and operational circumstances, wind can be utilized to produce forces that could act as an substitute source of power, making it an environmentally approachable source of additional energy that is well-matched with all fuels and propulsion arrangements. (Khan et al., 2021)

For the shipping industry, a variety of wind propulsion technologies have been created and are now under development. WAPSs have been fitted as retrofits to a variety of ship sizes and kinds as well as on newly constructed boats. Even though there are currently relatively few ships that are either equipped or scheduled to be outfitted with WAPS, there has been a noticeable increase in the use of this technology over the past ten years.

An additional promising long-term measure is the **carbon capture and storage or CCS.** The application of CCS can be established with multiple ways.

The on-board carbon capture works in shipping by firstly with the capturing process with pre- or post-combustion capture of CO2 emissions from ship engines. Several techniques, including membrane separation, adsorption, and chemical absorption, can be used to accomplish this. For the storage part the compressed CO_2 is kept in tanks. The purpose of these tanks is to securely hold CO_2 until it can be offloaded.

The CO_2 is offloaded from the ship and taken to a storage location as soon as it arrives at port. Trucks, ships or pipelines can be used for this purpose. After that, the CO_2 is injected into geological formations to be permanently stored, such as deep saline aquifers or exhausted oil and gas fields.

Phase 1 of Northern Lights, which unites TotalEnergies, Shell and Equinor to build cross-border CO_2 transport and storage for emitters across Europe, is one of the few definite projects now underway. It is planned to open in 2025 as a section of the Longship full-scale CCS pilot project, which is supported by the Norwegian government and contains a strengthen mill near Brevik. Furthermore, Northern Lights has agreements with Ørsted in Denmark and Yara in the Netherlands for the CO_2 offtake of a combined 1.6 million tons per year for phase 1.

Additionally, the Norwegian government has granted Equinor a 100% license to use the Smeaheia CO_2 storage facility on the Norwegian Continental Shelf. By 2028, the project intends to pump 5 mtpa of CO_2 from clients across Europe. The company's overall goal is to create value chains for the transportation and storage of CO_2 by 2035, with a capacity of 30–50 million tons of CO_2 annually (Equinor share).

Lastly, maritime industry is actively considering alternative fuels as one the most promising measures for the long run and for reaching broader decarbonization strategies by 2050. The development and attempts for adoption of alternative fuels is important taking also into consideration the complexities and challenges of maritime industry. A brief presentation of potential alternative fuels is provided in the next chapter. In general, the future long – term measures the we are expecting to see are new/innovative emission reduction mechanisms.

5. Alternative Fuels

The latest IMO MEPC 80 has provided a new round of greenhouse gas (GHG) emissions reduction goals for the maritime industry. The new set of goals is leading the sector to transform from conventional fuels to zero or near- zero GHG fuels by 2050.

Fossil fuels have been the leading source of energy for the global commercial fleet. The selection of fossil fuels has been defined throughout the years mostly due to availability, energy density and economic factors. Nevertheless, the maritime transport industry has come under growing pressure to enhance its environmental performance and reduce emissions that arise from fuel consumption.

Shipowners at the moment have a variety of options regarding oil fuels, including heavy Sulphur fuel oil (HSFO), very low Sulphur fuel oil (VLSO) and marine gas oil (MGO). They have also the option to choose lower-carbon alternatives such as liquefied natural gas (LNG) or use biofuel blends in their engines to minimize GHG emissions. There is also availability for ethane and liquefied petroleum gas (LPG) who are being used by carriers that are designed for those specific cargoes. The alternative fuels that will be presented below are the MDO/MGO, LNG, LPG, Methanol, Biofuels, Hydrogen, Ammonia, Batteries, Synthetic Methane and Nuclear.

5.1. MDO/MGO

The acronym for Marine Diesel Oil is MDO. It is a kind of fuel that is mostly utilized for smaller boats as it has adequate performance qualities and is considerably less expensive. Larger ships usually employ MDO for their auxiliary engines, which provide power to different equipment and systems within. Low-sulfur fuels, such as MDO, are necessary for ships operating in designated ECAs in order to abide with environmental restrictions designed to minimize air pollution. MDO is more advanced than heavy fuel oil (HFO) but less refined than marine gas oil (MGO) since it is a combine of distillates and residuals. Because of this balance, it can still meet some environmental standards and be a cost-effective solution.

Made from the lighter fractions of crude oil that evaporate during the distillation process, **MGO** is a distillate fuel. As a result, when compared to heavier fuels like Heavy Fuel Oil (HFO), it burns cleaner.

MGO is also used to generate electricity and heat on board, ensuring that ships have the power they need for a variety of tasks. Because MGO has less sulfur than HFO, it emits fewer hazardous emissions, which makes it a better option in places where environmental restrictions are stringent.

5.2.LNG

Glutra, a Norwegian car and passenger ferry, used LNG as its primary fuel in 2000. Following Glutra, other Norwegian ferries and offshore service vessels began using LNG as a fuel. The usage of LNG as a maritime fuel has increased dramatically in recent years. As a liquefied gas, it occupies a volume equivalent to 1/ 600 of the product in a gaseous condition, making it space-efficient to be stored on-board ship as a bunker. (Calderón et al., 2016)

The benefits of adopting LNG are more environmental than economic. LNG combustion on ships might eliminate SOx emissions while significantly reducing NOx, particulate matter, and GHG emissions. However, its CO2 emissions reductions are insufficient to address climate change notably. LNG lowers a ship's CO2, NOx, SOx , and PM by 85 – 90 % , 100 %, and 15- 20 % respectively , in comparison to HFO. On the other hand, LNG requires more fuel to produce the same amount of electricity as conventional oil due.

5.3.LPG

By definition, any liquid mixture of propane and butane is referred to as liquified petroleum gas, or LPG. In the United States, propane is typically linked with the word LPG. To get the required saturation, pressure, and temperature characteristics, certain butane and propane mixes are used.

The World LPG Association reports that 284 million tons, or 310 million tons of oil equivalent, of LPG were produced worldwide in 2015. This is marginally more than the demand for marine gasoline worldwide. Over the past ten years, production has increased by about 2 percent on yearly basis. Middle Eastern and North American production has increased at the greatest rate. Merely 9% of LPG is utilized as transportation fuel for vehicles, with half of that percentage occurring in South Korea. Refineries, the chemical and other industries and residences (for cooking and heating) are among the various instances that LPG is used. Asia is the region with the highest percentage of LPG consumption. If the demand for LPG as ship fuel grows gradually at first and stays at a moderate level is anticipated that the demand for shipping can be safely met until 2030 at the current production level. CO2 emissions from burning LPG are around 16 percent less than those from burning HFO. The CO2 savings come to almost 17% when the full life cycle, which includes fuel production, is taken into consideration.

Butane and propane have three to four times the potential to cause global warming as greenhouse gases than does CO2. When discussing the possibility of unburned LPG leaking into the atmosphere, this needs to be taken into account. LPG usage also almost completely removes sulfur emissions. It is anticipated that LPG will also considerably lower particulate matter (PM) emissions. The technology used determines how much less NOX is released into the atmosphere.

5.4. Methanol

Energy density as mentioned in all the is one of the major properties of a fuel and mentions the heating value per unit volume of fuel. The energy density is a significant design element as it influences the fuel tank size, and it is essential for ships that have important spatial limitations. Methanol has a decreased energy density in comparison with conventional fossil fuels such as gasoline and diesel, but an increased energy density compared to ammonia and hydrogen.

Methanol has the benefit of being in liquid form at a specific pressure and temperature, having the ability to be handled in a simpler way compared to LNG and hydrogen which need cryogenic temperatures to be carried as liquid. (Register K. , 2023)

Since the 1980's methanol has been used in commercial settings as a fuel. However, due to alcohol's low cetane number and lengthy ignition delay, methanol - blended fuels have been utilized for conventional compression ignition engines instead of pure methanol.

The amount of methanol in mixed fuels is usually 5 -30%, and phase separation must be avoided with the application of additives. As of late methanol engines that run on a small quantity of pilot fuel are being developed as dual- fuel engines that can run on methanol.

5.5.Biofuels

Biofuel is a general word for energy sources that has as an origin the processing of freshly created organic material, more simply described as non-fossil sources. Biofuels are obtained from feedstock biomass such as plant substantive, algae, vegetable oils and fats from animal waste and they often can be solid, liquid or gaseous.

There is a wide range of biofuels generated through distinct methods using a broad range of feedstocks. The most known products, adequate for shipping are:

Fatty Acid Methyl Ester (FAME), (specified by the specifications of EN 14214 and ASTM D 6754), often mentioned as biodiesel and,

Hydrotreated Vegetable Oil (HVO), (specified by the paraffinic fuel specification EN 15940), a synthetic diesel also known as green or renewable diesel.

The primary obstacles to the general use of biofuels are their long-term scalability and worldwide readiness, as well as the variety of feedstocks and handling techniques involved in their production. For both FAME and paraffinic goods, demand rivalry from other transportation and industrial segments is anticipated to grow in the ensuing decades. To boost customer certainty and free up additional feedstock for manufacturing, accreditation systems must tackle sustainability concerns about the amount of land and water used in feedstock fabrication.

For many ships, biofuels provide an option to reduce greenhouse gas emissions when upgrading other alternative fuel capabilities would not be financially feasible. The target of a ship operator to apply biofuels cannot be determined solely by looking at the orderbook because many biofuels are drop-in. The orderbook does not indicate the biofuel capabilities of marine engines in the same manner as, say, LNG-capable or ammonia-capable boats, despite the fact that biofuel ready notations do exist, and the majority of marine engines can use biofuels without alteration.

The readiness of the fuel and scaling up of production to match the enormous fuel amounts needed to substitute conventional fuels are the key obstacles to the general use of biofuels in shipping. The readiness of feedstock limits production volumes, while the order from rival fuel consumers and feedstock readiness affects biofuel pricing. (Register L. , Fuel For Thought : Biofuel)

5.6.Hydrogen

One of the advantages that Hydrogen provides is that while burning there is no release of CO2, particular matter (PM) or Sox, nevertheless its accessibility and low volumetric energy density involves important extra structure and system design. Hydrogen is able to be used as a mix in present conventional diesel fuels generally used in the shipping industry or as a fuel in fuel cells. The use of hydrogen in marine diesel engines is feasible at low levels of combination without major risks of engine damage. The global demand for pure hydrogen has increased and is still growing, therefore there is a belief that hydrogen is here to stay for the long run. The cost of hydrogen is the most challenging particularly for green hydrogen, as hydrogen does not have a specific design and fueling method for ships and its bunkering setup. For the time being we have in place two ways of producing hydrogen: by steam methane reforming and water electrolysis. (Jonathan Pierre et al., 2022)

Hydrogen has a particular explosive nature and is an element that needs to be highly considered. In this view, the wider acceptance of it, is a difficult path and any safety and reliability issues need to be addressed. Hydrogen holds an increased capital cost of storage, and onboard a hip there is a loss of cargo-carrying capacity. In order to progress hydrogen's effectiveness compared to other alternative fuels there are important improvements on capital cost of storage and onboard storage issues that need to be resolved.

5.7.Ammonia

One of the most promising in the medium to long term fuel in the alternative fuels field is ammonia. Investigating the reasons why ammonia has this wider acceptance, we can see that firstly green ammonia has a faintly higher volumetric energy density than methanol and considerably higher than hydrogen. This makes ammonia a much more desirable fuel for both deep-sea and short-sea journeys. Ammonia has as an advantage the ability to be in liquid form under pressure at 08. MPa at 20 ◦C of temperature, or at atmospheric pressure at − 33 ◦C, makes a vast difference when it comes to transportation and storage. Ammonia is a fuel that can be used in both fuel cells and combustion engines. As methanol has related characteristics with, ammonia is far more desirable option as it contains 40 % greater hydrogen than methanol.

What makes ammonia a very competitive fuel is the maturity and readiness when it comes to infrastructure, production, storage and transportation as ammonia has been used for a long term in fertilizer production. Nevertheless, and even if ammonia has higher maturity there are still modifications needed for storing and distributing the bunker fuel. (Hub, 2023)

Apart from all the advantages considered we need to take into consideration when discussing for ammonia that is very toxic for the humans as for the organisms existing in the water. Diesel and methanol have significantly less toxicity than ammonia. Ammonia although is poor in flammability it can cause explosion when exposed to high heat. Therefore, there is an emerging need for safety protocols and regulations that will spread public awareness for the use of ammonia.

5.8. Batteries

Batteries and hybrid power plants are revolutionizing energy use and distribution on ships. Using batteries in electric power systems allows for more control and optimization of performance, safety, and efficiency. As ship power systems become more electric and battery technology advances, new opportunities arise.

While fully electric ships constitute a significant advancement in power system design, they are now only practicable for specific uses like ferries and short-sea shipping. Other vessels may not be able to operate entirely on electric power due to battery system size or cost constraints. The limits of battery system apply to a variety of applications.

Batteries do not require the same infrastructure as traditional energy sources due to their lack of consumption expenses. Battery systems aboard ships require charging infrastructure. Depending on the application, battery size and charge time can impact power requirements. The automative industry drives battery production and cell development. The infrastructure is improving and equipped to accommodate increased demand from the maritime sector. The presence of maritime-focused enterprises indicates a robust manufacturing infrastructure.

Although batteries emit no pollutants when in use, their creation requires significant energy. Several studies have examined the CO2-equivalent emissions from conventional and battery system life cycles. Batteries provide significant environmental benefits in the maritime industry.

5.9. Synthetic Methane

Synthetic methane differs in that it is manufactured from recovered carbon dioxide and hydrogen generated by renewable electricity. It has the potential to replace natural gas in all scenarios in a more sustainable manner. Especially in sectors such as heavy transportation, shipping, and other business where gas utilization is often required. Synthetic methane can already be manufactured, and to some is the ideal solution for meeting those kinds of demands while reducing our environmental effect.

Synthetic methane has the advantage of local- energy self -sufficiency as it can be made from locally sourced materials and increases the energy independence. In addition, synthetic methane considerably cuts emissions, which aids in the fight against climate change. Using current infrastructure guarantees a quick transition to synthetic methane taking into consideration that synthetic methane can be delivered in many different forms, even over long distances, without significant energy loss.

6. Existing barriers facing alternative marine fuels

The barriers for the implementation of the alternative fuels in the shipping sector have a certain complexity and it exists in multiple levels such as demand and supply chains and infrastructure, economics and financial, the maturity of the rules and regulations but also the possible commercial implications faced for the implementation of them.

The **nonexistence of specific demand for alternative fuels** but also the readiness of key stakeholders to pay is one of the existing barriers that the implementation of alternative fuels is facing. For instance, it is still unknown the quantity of methanol that will be used for the dual-fuel ships that have been ordered until now. The successive delivery of methanol fueled ships, especially containerships, could lead to a peak demand of 4.5 million tons by 2026. Nevertheless, fuel providers could possibly face major problems taking under consideration the unpredicted market dynamics that could lead to significant lower demand, making fuel providers not confident to proceed with main investments.

Simultaneously carriers are unsure regarding the timing that the anticipated zero-emission fuel will be accessible, the places that it would be available, the quantities and which will be the ultimate price. Given these observed risks, carriers may be unwilling to enter into long-term fuel-offtake contracts. Previous conversional fuels have been used from the industry mainly to the fuels "cheap" nature as a way to have the lowest operational cost having the ability to be extra competitive in a rather strict-margin industry. Having that in mind the alternative fuels implementation has a much higher cost for which carries will only be able to "suffer" if they transmit the cost to their end customers. Persuading the end customers to pay the green premium will not be easy as the necessary mechanisms have not been developed yet and there is not enough clarity and openness on the price levels.

In the demand-supply relationship, it is necessary to take under consideration that alternative fuels are not a solution only for the shipping industry but there are also other sectors that are looking over. These differential outcomes are determined by the comparative commitment to pay the extra among potential end users. In the short run, when commitment is low, there will be elevated chances for collaboration to cumulative demand and reduce prices.

Another existing barrier that arises by the potential use of alternative fuels **is the economic and financial constraints**. The primitive costs linked with the implementation of alternative fuel ships come from shipbuilding costs, fuel costs and from the implementation costs of any regulatory requirement. (ClassNK, Semptember 2024)

To comply with IMO's and EU regulations shipping industry needs to burden with regulatory costs that will resulting from GHG emissions and fuel use. Ships should monitor their emissions and identify possible ways of reducing them through fuel transition, with that way regulatory costs estimation will be much more accurate. EU regulations are targeting GHG emissions in EU-related voyages, while IMO regulations can cover GHG emissions in all voyages. Accordingly, the regulatory expenses burden may be comparatively higher needing consideration. (Sorrell et al., 2004)

Another issue that could be considered as a challenge for the implementation of alternative fuels **is the understanding and consideration of the maturity and of the maritime rules and regulations**.

It is common that the maritime industry follows strict guidelines for ship construction and operation. These guidelines enhance safety and consistency while safeguarding the environment. The new technologies and alternative fuels that are considered to assist in the decarbonization of the shipping industry are having unique chemical features, such as low flash points, greater toxicity, instability, and non-compatibility, which maximize the possibilities of uncertainty and dangers which also comes from the lack of training of personnel. (Acciaro and Hoffmann, 2013) In this view, the establishment of new norms and standards is mandatory. Safety, consistency and protection of the environment should be a priority during the implementation of those new technologies. The industry initially will follow a risk-based methodology and will take out the necessary knowledge and afterwards enhance procedures. Nevertheless, it would be more efficient if the industry implements sooner a more structured system with consistent frameworks related to ship design, ship operations, fuel standards, bunker management plans, workforce and personnel factor, training and competence standards and safety management systems for the proper implementation of alternative fuels.

The implementation of alternative fuels is also causing **commercial implications**. Alternative fuels are responsible for minimizing of cargo loading capacity, adding difficulty concerning the bunkering of the vessels and fuel amount for voyage. For instance, methanol can be stored in new fuel tanks or to already existing ballast water tanks. In case there has to be use of additional tanks, those must also be placed on the ship minimizing in that way the available cargo loading space. Some of the alternative fuels also need special tanks in order to be stored considering the special design and the number of large spaces that need to occupy either on deck or under deck.

Given the density and lower heating value of every fuel differs, the amount of fuel needed depending on the fuel for the identical voyage is different. As an example, methanol and ethanol while having identical density with conventional diesel fuel they are having half lower heating value compared to diesel. Therefore, we need the double amount of methanol and ethanol in order to have the same quantity of heat release. On another instance and example of alternative fuel hydrogen does not require to be stored on board and can be produced depending on the demand by using alkaline electrolysis system. Hydrogen does not occupy extra cargo loading space.

The bunker procedure and availability in ports is something also to consider as it would need proper scheduling in order to avoid implication in the route of the ship. There will be cases where the port may not have enough bunker to supply and the ship will have to change its route, occurring to major delays. Not all alternative fuels are bunker capable. Hydrogen is the most adequate one with methanol and ethanol described as the least capable.

All the above challenges should be addressed and are requiring collaborative actions from all stakeholders involved if we want to see the alternative fuels work as tool for minimizing GHG emissions and lead shipping industry to sustainability.

During the following years, the industry should be able to follow all alternative fuel pathways by succeeding in technological readiness for the production of alternative fuels, expanding regulatory standards in order to support the use of alternative fuels, securing the safety on board and on land for bunkering and operation of alternative fuels and in that way secure that the right infrastructure but also competencies will be in place.

7. The role of ports in decarbonization

Ports and terminals are crucial nodes in the maritime transport network. Ports are a major source of pollution due to their heavy use of fossil fuels and high emissions from maritime shipping.

Ports have a crucial role in mitigating climate change by reducing GHG emissions, particularly carbon emissions. This is due to rising environmental concerns. Multiple variables contribute to port pressure. One variable is international regulations on air quality and climate change mitigation affect port authorities, operators, tenants, and inland transportation systems. Second variable is local regulations, such as California Air Resource Board (CARB) and EU regulations.

Resolution MEPC.323(74), adopted by the International Maritime Organization (IMO) on May 17, 2019, encourages voluntary cooperation connecting the port and the various stakeholders of shipping sector to reduce greenhouse gas (GHG) emissions from ships. The key points presented in this resolution are a) promoting the use of and capability of business cases for ship and in-port renewable power-to-ship systems, b) promoting collaboration between main stakeholders (ports, bunker suppliers, shipping companies and all applicable levels of authority to address the supply of all alternative fuels , but also to address legal regulatory and infrastructural barriers for the competent use and safe handling of alternative fuels, c) encouraging incentive arrangements that address GHG emissions and sustainability of worldwide shipping and encouraging more incentive providers and shipping companies to join these; and lastly to d) support the industry's joint efforts to progress excellence and accessibility of data and grow necessary global digital data standards that would permit consistent and effective data exchange between ship and shore as well as improved slot provision policies thereby improving voyages and port calls and enabling just-in-time arrival of ships

We need to consider **three main categories** of Port GHG Emissions Reduction and Energy Efficiency strategy. The first category contains the **portside measures**. The second refers to **ship-port interface measures** and the third category refers to **land transport.** (Alamoush et al., 2020).

7.1.Portside Measures

We can define five main categories of **portside measures. Information measures, Equipment measures, Energy measures, Energy Efficiency measures and lastly Operation Measures.** (Alamoush et al., 2020).

Portside Measures
✓ **Information Measures (Emissions inventory and tracking, Air quality monitoring (e.g., Port of Los Angeles, Shanghai))**
✓ **Equipment Measures (Replacing fossil-fueled equipment with clean energy alternatives, Electrification of cranes, forklifts, and yard tractors).**
✓ **Energy Measures (Adoption of alternative fuels (e.g., LNG, methanol), Solar, wind, and geothermal energy production).**
✓ **Energy Efficiency Measures (LED lighting and green building standards, Hybrid systems combining conventional).**
✓ **Operational measures (Digital technologies, Container terminal automation and operation system (TOS), Port city integration and green policies).**

Information measures include inventorying emissions and energy, as well as monitoring and reporting on them. Following an inventory of emissions and energy consumption, ports establish an emission baseline and continue to collect emission data, tracking and reporting emissions over time. The port information measure reduces emissions from ports, ships and trucks.

Monitoring air pollution is crucial for implementing environmental measures and controlling external consequences of port activities. This helps internalize port emissions and account for the external cost of shipping emissions, thereby boosting the port's green image. (Agency, 2024)

The Port Emission Inventory provides data on greenhouse gas emission sources and intensity, allowing port operators and management to make more informed governance decisions. In the interim the inventory can help track and evaluate these measures. The Port of Los Angeles in the US established an emission inventory in 2005, which serves as the scientific basis for air pollution management measures. Inventory is updated annually. Shanghai, Shenzhen, and Tianjin ports in China have produced a specific inventory of air pollution source emissions. The last two ports carry the most recent version of the inventory in 2020.

Monitoring air quality and pollution sources at ports is crucial for assessing the impact of pollution reduction efforts. Set up air quality monitoring station to check the port's air quality in real time or on a regular basis. To improve port air quality, it's important to establish defined standards. Ports throughout the world, including Los Angeles and Long Beach in the US, have been doing this for over a decade. In China three ports (Tianjin, Qinhuangdao, and Huanghua) have made their air quality conditions public.

Equipment Measures Port equipment initiatives involve replacing aging equipment and converting fossil fuels to clean fuels, minimizing carbon emissions. Port managers have steadily replaced old equipment with new energy sources or engines as part of their automation efforts. Automation will require equipment modification in the future. The San Pedro Bay Ports Clean Air Action Plan calls for the replacement of some older Cargo Handling Equipment (CHEs) with new clean engines over a set time span. Container port operators in New York and New Jersey (NYNJ) replace yard tractors with new equipment every five to ten years. The terminal operators update locomotives and invest in the replacement of obsolete diesel-powered gantry cranes with features that use regenerative electric capabilities, backed up by a compelling commercial case. However, repowering and replacement programs for the CHE are costly and manufacture and transport to ports is difficult and time consuming.

Energy measures include the use of **clean fuels, renewable energy and alternative power sources**.

The selection of **alternative fuels** for the ports is often related with the specific infrastructure that is already in place but also the regulations local and international that each specific port has in place. Ports can employ alternative fuels to power equipment and establish production plants for their own suppl.

Biofuels, methanol and hydrogen are all set as promising alternative fuels for the use in ports with their advantages and challenges. Nevertheless, LNG seems to get ahead of other alternative fuels mostly to a series of advantages such as availability, infrastructure and specific use cases. LNG storage and bunkering infrastructure is already available in many ports. Additionally, LNG emit less SOx, NOx and particulate matter than typical marine fuels.

Following the request to minimize emissions and engage all stakeholders with sustainability alternative fuels have a variety of use in ports such as bunkering services which involves customized fueling stations storage capacities for the use of alternative fuels such as LNG, methanol and ammonia. Additionally, ports can provide shore side electricity which is called also cold ironing to the vessels that are berthed. The main issues that cold ironing raise is the airborne emissions while the onboard auxiliary generators are turned off.

Alternative fuels can also be used for powering port equipment. There are various categories of port equipment such as forklifts, cranes, yard tractors, other cargo handling equipment such as straddle carriers, reach stackers etc.

An additional category of the energy measures is the **alternative power systems** such as electrification and hybridization.

Electrification refers to the process of substituting electric alternatives for conventional fossil fuel-powered machinery and infrastructure. This may include cargo handling equipment such as electrifying cranes, forklifts and additional machinery equipment used for the discharging of the ships. Electrification also refers to the utilization of electric vehicles (EVs) which are related with the small routes that are taking place within the port. Lastly electrification has as a part of its implementation the allowance to ships to plug in to the port's electrical grid while the ship is berthed, serving the purposes of minimizing the need for diesel engines. (Pacific Northwest National Laboratory, 2024).

Port electrification can greatly minimize the environmental impact of maritime activities. Replacing fossil-fuel-powered equipment and vessels with electric alternatives can significantly reduce greenhouse gas emissions, air and water pollution, and adverse environmental health effects on port workers and surrounding populations. Additionally, electrification can reduce cost notably for the port operators for the long run. Although electric equipment may need a considerable initial investment, it is often more energy efficient, less costly to operate, and can make a significant saving on fuel expenses, helping in general operational savings over time. If a port generates electricity on – site, the electric company may provide programs to sell excess generation back to the grid. (Pacific Northwest National Laboratory, 2024). On the other hand, port's ability to electrify depends on their operating structure, even if they have high goals. Landlord ports must work with tenants and other stakeholders to electrify port operations. Tenants often take the lead on electrification projects.

Ports have varied levels of influence over the activities they support, based on their structure (e.g., landlord or operational) and regulatory environment. Port electrification regulations vary at national and international levels, making it problematic for ports serving varied consumers. (Pacific Northwest National Laboratory, 2024)

Hybridization is used to establish more competent systems by uniting traditional fuel engines with electric power. The ways that hybridization can be achieved is either through hybrid cranes and vehicles, through a combination of convention fuels and electric power. Another way that this can be achieved is by energy storage systems. Regenerative braking in cranes are a way of capture and reuse energy.

Ports can use **renewable energy sources** such as solar, wind, tidal, and geothermal. Port's strategic placement helps meet the growing need for renewable energy. (Liping Zhang et al., 2024).

Solar energy production can be photovoltaic or solar water heating (SWH). Solar PV (Photovoltaic) is an accepted generation resource to consider as renewable energy source. Solar energy has higher production during the summer than in the winter. Several well-known ports, including Amsterdam, Tokyo, Antwerp, Felixstowe, and Santiago using photovoltaic technology. If land permits solar panels are built in open fields and on rooftops or cruise terminals, buildings and warehouses. Another practice is being followed for the Solar Water Heating procedure (SWH) which warms water or oil and stores it in tanks. Installing panels on port building's roofs reduces energy costs for heating buildings, showers, canteens and warehouses. (Liping Zhang et al., 2024). Geothermal energy harnesses the energy stored inside the Earth's layers. Heat generates electricity; moreover, both heat and cold are used to heat and cool workplaces, warehouses, and buildings. Near surface geothermal energy is used in EU ports.

Another category of portside measures is the **energy efficiency measures.** The energy efficiency measures do include **energy saving measures, energy management systems and technologies.** (Alamoush et al., 2020).

Energy efficiency initiatives at ports can reduce energy consumption and shift to renewable energy, lowering GHG and CO2 emissions. These emissions are directly proportional to fuel usage. Energy efficiency measures have as a final goal to reduce energy waste. Energy consumption efficiency has come second as a measure with first environmental priority being air pollution for EU. European ports created energy efficiency programs while using renewable energy measures.

Among the **energy saving measures** is the replacement of existing lighting with energy- efficient LED lightning in the various port areas and warehouses. Another initiative that can support the energy saving measures is the construction or retrofitting buildings to meet green building standards which incorporate energy- efficient heating, ventilation and air conditioning (HVAC) systems.

Energy efficiency measures do also include the **energy management systems and technologies.**

Energy management systems bring in electrification, automation, hybridization, Onshore Power supply (OPS), alternative fuels, renewable energy and advanced technologies like energy storage systems, smart grids, microgrids, virtual power plants and smart load management.

In the context of a port, energy storage systems are technologies and solutions that store energy to use in later stages. These systems are aiming in managing energy supply and demand increasing efficiency and facilitating the incorporation of renewable energy sources. Here are some major types of storage devices widely used in ports:

Battery Energy Storage System (BESS) is rapidly gaining popularity in ports. This is mainly due to its scalability, adaptability, and quick response. Furthermore, using lithium-ion or flow battery technologies, BESS installations can vary greatly, from regional to enormous utility-scale deployments. BESS captures and stores excess renewable energy for eventual release, ensuring a reliable power supply. They also provide critical backup capacity during grid disruptions, which improves operational resilience and continuity.

Thermal Energy Storage Systems are systems which store energy in the form of cold or heat. These can have a variety of utilization. It includes heating, cooling, and industrial processes as well. In the use of ports, TESS can be used to store excess heat or cold. These can be generated during port operation or from sources of renewable energy. TESS can be particularly useful for ports located in areas with significant temperature variations, as they can provide heating or cooling as needed, reducing the energy demand and associated emissions from conventional heating and cooling systems.

Other technologies such as smart grids which is considered as an upgraded electrical grid that employs digital communication technologies to monitor, control, and optimize electricity generation, distribution, and consumption. It combines a variety of modern technologies to improve the power supply's dependability, efficiency, and sustainability. Smart grids include automated systems record data in real time, allowing them to manage supply and demand swings more efficiently. They can identify and respond to power outages and defects fast, typically restoring power immediately.

Microgrids and **smart grids** may appear similar at first look, but they are very distinct. Both are advanced energy technologies that ensure grid resilience and stability, allowing for efficient electricity distribution. Microgrids are localized energy systems that increase resilience and sustainability while fostering local sovereignty. They come in a variety of microgrid configurations that can operate independently or in conjunction with the main grid. Smart grids use digital technologies to create an adaptive grid that integrates several energy sources. This shift toward decentralization secures a stable and sustainable energy future. (Wang et al., 2023)

Another element of the energy management systems is **Virtual Power Plants (VPPs).** VPPs are an innovative option for energy transition and sustainable power generation transforming modern power systems. VPPs play an important role in enhancing efficiency, flexibility, and resilience in the energy industry by integrating many energy sources and improving grid management.

A VPP is an emergency management system that incorporates several distributed energy resources (DERs) such as photovoltaics, wind turbines, BESS and demand response technologies. A VPP optimizes the gathering of distributed energy resources (DERs) based on grid circumstances, demand, and market signals. VPPs utilize complex control algorithms and real-time monitoring to optimize energy dispatch schedules, balance supply and demand and improve grid stability and dependability. (Wang et al., 2023)

VPPs and smart grids share some fundamental similarities. Smart grids strive to modernize the entire electrical supply chain, while VPPs focus on aggregating and optimizing DERs. The VPP provides auxiliary assistance to the smart grid such as supply and demand balancing.

Digital technologies are one of the technologies used as **operational measure** from the portside. Blockchain and cloud platforms are now widely used in maritime supply chains and ports. These digital technologies make it simpler and easier to build effective links and share information between various institutions, including shipping corporations, ports and terminals, customs and shippers. Using these technologies, it is feasible to efficiently monitor the entire operational process in ports, enhance communication efficiency and speed up operational procedures. As a result, needless transit, warehousing and inventory at ports can be avoided, resulting in significant reductions in energy usage and carbon emissions.

In port seafront regions, digital technology allows for the construction of port layouts and accompanying structure to reduce ship travel distances and enhance vessel speeds between port entry and exit, lowering that way carbon emissions from ships within ports. Furthermore, by combining digital technology with ship trip data and weather conditions, port operations can be adjusted in real time, reducing economic losses and environmental pollutants caused by inclement weather. Furthermore, digital technology allows for thorough monitoring of ship status in ports, which is critical for garbage discharge and marine pollution control.

Equipment such as container cranes are playing a significant role in high GHGs that come in port land areas and yard areas. Enhancing the operation of cranes providing actual monitoring of cranes with a real-time contribution and energy utilization, assist in adjustments that improve energy efficiency. Apart from the cranes the actual remote monitoring and supervision of robotic vehicles is possible and helps their monitoring and reducing of energy consumption.

In general, this promotes collaboration between autonomous guided trucks and other port equipment, resulting in better container handling operations while reducing energy loss and carbon emissions. Furthermore, digital technology provides comprehensive insights into the availability of empty containers at port facilities and the status of terminal vehicle operations, allowing for the optimization of truck arrival times at port gates and the reduction of waiting times outside yard gates, thereby reducing greenhouse gas emissions caused by truck congestion.

Certainly, digital technology offers enormous promise for aiding the development of green ports. Nonetheless, the development of digitalization in port infrastructure presents considerable hurdles. A major obstacle is the high expenses associated with infrastructure development, which necessitates thorough cost-benefit analysis by port management authorities and operators. Furthermore, competently organizing, analyzing and utilizing various data is a critical focus. This requires the combined use of data gathering tools, big data analytics, and artificial intelligence. Defeating these problems helps ports to improve their efficiency and environmental sustainability.

An additional operational measure that is linked with the portside activities is the **Container terminal automation and operation system (TOS).** Container terminal automation includes the utility of progressive technologies in order to support functionalities within the terminals such as movement and storage of containers. The implementation of automation includes the automated stacking cranes, automated guided vehicles (AGVs) and automated straddle carriers. (Martín-Soberón et al., 2014).

Those automated devices are being used in order to relocate containers from the vessels to accommodation locations and the other way around. The container terminal automation does also include smart and complex software that monitor and improve terminal activities. They oversee the procedures of container movement, storing and recovery, succeeding with that way the most effective use of area and sources. The automation of those systems has given the possibility to vessels to perform loading and unloading procedures in the most efficient and quick way minimizing the turnaround time for vessels.

Port city integration and green policies are also part of the operational measures for the Ports. Port-city integration projects seek to improve the interaction connecting ports and the surrounding metropolitan areas, thereby fostering the economic development of the area. Ports can be transformed into waterfront places through initiatives such as cultural regeneration projects. By combining port actions with city development and community growth, port communities may capitalize on their nautical legacy to create appealing living, working, and entertaining places while safeguarding historical and cultural resources.

Apart from the technical and operational measures that ports are trying to implement, there are also **green policies** and programs that they are trying to establish. There are initiatives where ports are choosing to purchase products that are originated from environmentally friendly industries. In this scheme there are also initiatives such as port personnel being supported and encouraged to use carpooling, van pooling public transportation and bicycling.

7.2.Ship-Port Interface Measures

Moving on to the second category of ports strategy referring to **ship-port Interface measures**. Ports can support with operational practices and emission decrease techniques to visiting ships, reducing emissions while in port. (Alamoush et al., 2020).

Ship -Port Interface Measures
✓ **On- shore Power Supply also known as cold ironing.**
✓ **Port alternative fuels bunkering infrastructure.**
✓ **Just In time (JIT) Berthing and Virtual Arrival techniques.**
✓ **Ship turnaround time.**
✓ **Allocating berths and yards.**
✓ **Vessel speed reduction.**

On- shore Power Supply also known as cold ironing. The procedure of cold ironing is described as the switch -off of the diesel engines forcing ship generators that are responsible for onboard load to switch to electricity provided from the shore while at berth. Cold ironing is a very well accepted practice for minimizing emissions as an alternative power supply source, nevertheless the implementation of this measure is quite underutilized due to the extensive costs that its implementation brings. (Najmeh et al., 2023). Ports should also take into account that there are various ship types all requiring different power supply and having different operational schemes.

Cold ironing offers significant cost savings in ports for ships that are staying longer. Ships with prolonged berthing hours should focus on emissions from auxiliary engines, as they continue to leak dangerous elements into the environment. Container ships use a significant percentage of the CI on- shore power supply because of their extended berthing time of 21 hours or more. Cruise ships are becoming increasingly popular due to their high-power consumption for 'hoteling' services, which must be secured throughout their stay at berth.

Port alternative fuels bunkering infrastructure is another measure that could support industry's goals in reducing emissions. Ships can perform bunkering in ports through on-site facilities to the ship or by performing ship to ship bunkering of vessels or from truck to ship. Most of the ports as of now do have in place bunkering facilities which correspond to traditional conventional fuels, extra bunkering infrastructure should be established in order to accommodate the new needs. The right timing for establishing the bunkering facilities should be examined thoroughly, as it would be necessary to have the infrastructures in place when the demand for alternative fuels will be high. However, there is also the possibility that investments are made into bunkering facilities for fuels that shipping companies do not actually use.

Just In time (JIT) Berthing and Virtual Arrival techniques are operational strategies that can optimize the arrival of vessels at ports. They can also reduce the emissions and fuel consumption of the ships. The concept of **virtual arrival** involves changing the vessel's speed to ensure that it arrives at the appropriate time when the port's berth is available. This method can reduce the emissions and consumption of the ship. It also retains the position in the queue according to the estimated arrival time.

Just-in-Time Berthing is a similar idea in which ships are programmed to arrive at the port exactly at the time that their berth becomes available. This reduces the amount of time ships spend waiting outside the port, which saves fuel and reduces emissions. It involves detailed management by effective coordination and communication among port officials, shipping corporations, and other stakeholders.

There are also other practices that can help reduce the emissions from the ships while at port such as **ship turnaround time.** Ship's turnaround time refers on how much time a ship spends on the port from the time it arrives until the departure including all the tasks docking, loading and unloading cargo waiting for berth and any other required operation. The quick turnaround time is essential for many reasons for shipping companies, but a fast turnaround time also serves the reduction of emissions from ship while in port. (Styhre et al., 2017)

Additionally **allocating berths and yards** strategically helps ports minimize emissions by facilitating the movement and management of cargo and vessels. Ships that are allocated berths effectively waste less idle time while they wait for a berth. Ships can modify their speed to arrive just in time, rather than rushing and then idling, by coordinating arrival times with berth availability. This decreases the quantity of fuel burnt and, subsequently, the emissions produced.

Also, **proper yard delegation** guarantees that containers are kept in the most efficient places, decreasing the distance and time needed for internal truck transfers. This results in lower fuel consumption and emissions from yard equipment. Successful yard supervision lowers terminal traffic, resulting in efficient and quicker operations. This minimizes the time vehicles and cranes consume idling, significantly reducing emissions.

Vessel speed reduction is also another operational measure that could be implemented from ships arriving to ports. Lower speed seems to work as a tool for increasing sustainability in marine operation. Port of Long Beach and Los Angeles have programs that direct oceangoing boats to slow down to a predetermined distance. (Goldman School of Public Policy, 2024).

7.3.Land Transport measures (Hinterland)

Land Transport Measures (Hinterland)
✓ Modal Shift/ Split (Waterway transport)
✓ Truck Congestion Reduction.

Lastly, we have the category of land transport measures or hinterland. (Alamoush et al., 2020). Due to the unique geography of the hinterland and the port, the hinterland serves as the foundation for the port's growth and progress. The hinterland's transportation network, economic growth, market size, and infrastructure improvement all have a significant influence on the port's modernization and revolution. The hinterland is where international trade commodities are supplied and where the port's neighboring industries sell their products, which influences the port's growth. It is important for hinterland to ensure that is also implementing green initiatives in order to support in the overall plan of sustainability. As emissions from port-related hinterland are solely the consequence of port activity, we need to address the responsibility to the port for assisting in green initiatives that have to do with the hinterland.

Some initiatives that can be addressed and are related with the port-hinterland is the reduction of air pollution that arises from road vehicles, reduce the noise from trucks tarin engines, minimize the traffic streams on connecting infrastructure and transfer traffic from the road to a less jammed mode (rail on inland waterway) enhancing with that way the use of two or more transport modes.

Waterway transport has a high cargo volume, cheap transportation costs, and is appropriate for wide-scale transportation, and these benefits have drawn a significant number of developers and investors to the hinterland region, resulting in capital accumulation and flow.

While transportation through road is flexible, fast, and adequate for short- and medium-distance transportation, it has a minor capability, great energy consumption, and high pollutant emissions, which are restricted to the interior of the port hinterland. These elements are combined with the advantages and disadvantages of road transportation. Its negative outcome outweighs its favorable effect on the port's direct economic hinterland, reducing the port's economic growth capacity. In the long run, it is detrimental to the beneficial and green growth of the hinterland's regional economy.

The procedure of gradually improving the green effectiveness of ports creates acceptable transportation and greening, as well as local ecological arrangements. Port logistics and transportation systems are becoming increasingly smart, green, and particular, which promotes the development and progression of hinterland logistics systems during the collaboration process, drives the creation of substructure and transportation network systems in the region, and improves logistics availability and rotation competence between ports and hinterlands.

Ports are looking over to have a broader rollout and acceleration of bigger and heavier vehicles (LHVs) to accommodate sustainability issues but also transportation costs. Adequate infrastructure and safety guidelines are necessary in order to facilitate this. Ports are examining and other options of use of night-time transport, truckparkings, specific freight lanes that help both within and outside the port area.

8. Readiness of American Ports in Decarbonization

8.1.U.S Ports Energy Transitions

There are many U.S cities that have been developed and built over the years around ports. Considering this, it is easy to understand that ports are significant for the communities that are built around them. Ports are providing extra jobs, securing the provision of goods and are a way to connect the communities with seaside. They are significantly connecting communities with leisure and activities for tourism. Despite the high activity that is being gathered around ports there are unwanted environmental impacts created around those activities, pollution, traffic, and uneven economic development. Ports in the region of U.S have a very important role in protecting sensitive coastal areas and providing resilience to climatic shocks and stressors. The worldwide biodiversity crisis puts an extra pressure on ports to improve and protect the environment. Recently, there are few U.S. ports that have set net zero or carbon-neutral goals.

It seems that there is a lack of specific framework that makes precise, how those goals could be achieved and does not make clear the accountability that key stakeholders should have but also the consistent reporting metrics. The immense diversity of ports and how this affects their decarbonization and environmental journeys must be considered in any assessment of U.S port decarbonization initiatives.

As indicated from various reports, many ports are developing action plans and decarbonization initiatives, although their scope, specificity, and quality vary greatly. Most of the ports included in the landscape scan have public decarbonization plans, strategies and targets. These include initiatives to improve investment access and a system- wide decarbonization strategy. The formality, complexity and level of public transparency of these strategies vary widely, ranging from fully thorough, well documented plans among a few major ports to more constrained public announcements or brief presentations from others.

There are US ports that operate in a more severe regulatory environment, speeding up their shift to zero – emission technologies, whereas other ports do not. For instance, the State of California has been a leader in the policy and regulatory realm influencing United States ports.

The **U.S. Environmental Protection Agency (EPA)** plays a significant role in improving environmental performance and sustainability at ports through various initiatives and regulations having as a key aim to make ports more sustainable and environmentally friendly, benefiting both the local communities and the broader environment. Not all U.S ports are implementing EPA regulation uniformly, but many are making significant efforts to comply with and exceed these standards. (Agency, 2023)

The implementation of EPA regulations can vary based on several factors such as port size and resources, the larger ports have the ability to adopt new technologies and practices more easily and adapt with the cost. State and local regulations may have stronger and more strict environmental regulation and therefore ports adopt their local regulations. Lastly, the ports that have a strong community commitment and stakeholder participation are often more proactive in adopting sustainable practices.

While there is a broad range of compliance, the trend is towards greater adoption of EPA regulations and sustainability initiatives across U.S. ports, driven by both regulatory requirements and voluntary efforts to improve environmental performance.

On March 2024, the U.S. Environmental Protection Agency (EPA) has launched the **Clean Ports Program**, funded by the Inflation Reduction Act of 2022. This program provides **$3 billion** to support zero-emission port equipment and infrastructure, as well as climate and air quality planning at U.S ports. (United States Enviromental Protection Agency, 2024).

The funding for the zero -emission technology deployment competition rises to approximately $2.8 billion and has as its main goal to secure new zero-emission port equipment and infrastructure, reducing in that way the mobile source emissions. The funding for the climate and air quality planning reaches the $150 million, in order to support climate and air quality planning activities, involving emissions, management and strategy analysis, commitment from the community and measures that will ensure the right resiliency.

The Clean Ports Program has as a main goal to create a framework for the port sector that will support the gradual transition to totally zero-emissions operations, giving the ports the opportunity to serve as a key stakeholder for the transformative change throughout the freight sector. Through this program US ports are expecting to reduce diesel pollution in the areas near the ports contributing significantly to a more healthy and sustainable community. (United States Enviromental Protection Agency, 2024).

Another regulation included in the scope of EPA's is the **Clean Air Act**. The Clean Air Act is a federal law that affects the entire country. However, states, tribes, and local governments conduct the majority of the work to meet the Act's requirements. (Agency, 2023)

The CAA is intended to protect public health and welfare from various forms of air pollution. It sets air quality standards and requires governments to create enforceable strategies to meet those criteria. The CAA has important implications for the port business, including laws on diesel engines, marine vessel loading operations, paint coatings, and emissions from cars and many forms of port equipment. Many of the vehicles and equipment used in port operations are in use for a long period. Often referred to as the legacy fleet (existing fleets of vehicles or equipment that were built before the adoption of newer, more advanced technologies) these diesel vehicles and equipment are not subject to EPA regulation under the CAA. The EPA's regulatory jurisdiction only includes the capacity to limit emissions from new cars and equipment.

EPA has additionally other programs that ports are getting involved such as the **Clean Water Act (CWA)** which aims to reduce pollutants in U.S waters and regulate discharges of pollutants into navigable waters. Ports must comply with these regulations to prevent water pollution. (Agency, 2023)

Additionally, EPA has established the **National Environmental Policy Act (NEPA**) that requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions. This includes projects at ports that may impact the environment.

Apart from the bigger ports that are leading those kinds of initiatives, progress to decarbonization activities is also happening by setting small near-term projects to operational emission that are related only with own port's infrastructure. Port authorities, owners and terminal operators often fail to have an all-inclusive approach. There are a lot of large U.S ports that provide to the public an emissions inventory in order to trace the development of their air emissions reduction programs including also some GHG emissions (carbon dioxide, methane and carbon monoxide) which is emitted only from port's infrastructure and equipment.

For the purpose of this dissertation, we are going to present the initiatives for the three ports that have led until now the attempts in the US region for minimizing GHG emissions from port's activities and assisted shipping industry achieve its goals.

Port of Los Angeles

The Port of Los Angeles is located on San Pedro Bay, 20 miles south of downtown Los Angeles. This prosperous harbor not only retains its competitive edge through record-breaking cargo operations, but it is also known for pioneering environmental initiatives, progressive security measures, a diverse range of recreational and educational facilities, and Los Angeles' burgeoning waterfront attraction. The Port encompasses 7,500 acres of land and sea, with 43 miles of waterfront. It contains 24 passenger and cargo terminals, including vehicle, break-bulk, container, dry and liquid bulk, and warehouse facilities, which handle billions of dollars of cargo each year.

The Port of Los Angeles is an excellent example of how a bustling, urban port might move to a zero-carbon future. Failure to act, instead has a high cost to human health and may result in other ports appropriate refueling points for zero-carbon fuel powered ships, resulting in a significant occasion fee for ports that remain inactive.

The Port has long relied on liquidized natural gas (LNG) as a transportation fuel. On May 8, 2009, the Port of Los Angeles Board of Harbor Commissioners approved $44.2 million in Port funds to purchase clean trucks. The Port's funding, together with money provided by municipal, state, and federal regulatory authorities, as well as private investment, helped put almost 900 LNG-powered trucks into service at the Port. The Port favors the development of LNG as a marine fuel.

Ports build onshore and offshore wind turbines, but space remains a barrier. Wind energy producers are located in various ports, including New Jersey, San Diego, San Francisco, Baltimore, Long Beach, Hamburg, and Zeebrugge. Offshore wind farms frequently use big generators that cannot be attached to the port's grid. As a result, ports have signed power purchase agreements with wind farm developers.

One of the initiatives of the Port of Los Angeles is a charitable partnership with other two prestigious ports the Long Beach and Shanghai port and few of the biggest shipping lines in the world named **Pacific Green Shipping Corridor.** The contribution of cargo owners in this initiative is very important in order to send a strong message across shipping industry that partnerships are the only way to move forward with reducing emissions and promoting sustainability. The role of this combined partnership group is to identify green shipping corridor goals, move forward as a lead the various stakeholder’s engagement and with that way succeed onboarding more new partners. (Angeles P. O., 2023). Main key for this partnership group is also to bring the implementation plan to a maturity level and develop it along with continuing corridor program administration and development.

Another big initiative of the port of Los Angeles is the **San Pedro Bay Ports Clean Air Action Plan,** which was joined on November 20, 2006, by the board of Port of Los Angeles and Long Beach. Clean Air Action Plan is the most inclusive strategy for achieving the reduction of air pollution and address health issues that arise from ports functionality.

The CAAP strategies are mostly concentrated to the below actions:

1) Clean Vehicles and Equipment Technology and Fuels: The key to sustainable goods mobility is the cleaner engine technologies. In order to maintain one of the cleanest fleets worldwide the ports have the commitment to enhance their zero-emission technologies. The State’s goal is to have in place 100,000 zero- emission vehicles by 2030 using methods

such as the Clean Trucks Program (CTP), which was implemented in 2007 and came into force in 2008, having as a main goal to replace and phase out the oldest and dullest trucks that were helping portal terminals by banning trucks that were older than 2007 engine model year (MY). (Angeles P. o., 2017)

2) Freight Infrastructure Planning and Investments: Investing in electrification and fuel infrastructure is crucial for implementing cutting-edge, environmentally friendly technology. Shifting cargo handling methods, such as maximizing on-dock rail, can help reduce emissions. There are plans that can reform Port's infrastructure and can assist to pursue zero emissions. Examples are the growth of the rail both while arriving and departing from the Port facilities. One way that can improve the transportation system is transferring cargo and freight to and from the port complex by train which can minimize truck mileage, overcrowding activities and pollutants. By loading cargo to the rail, it helps raise more money and save time by minimizing the need of lifts to off-site facilities. Another plan that is considered as freight infrastructure planning and investments is the assistance to Electric Terminal Equipment by having charging standards.

   The successful implementation of this requires infrastructure of electrical charging. For the time being producers of electric terminal equipment are having in place dissimilar approach and each equipment has different design specification to charge the vehicles making this diversity on specifications requires to have different infrastructure requirements. This kind of variety raises the future challenges in the long run. To install electric equipment on a broad scale, the ports must establish charging criteria so that uniform arrangement can be built throughout the port complex and a range of equipment made by multiple manufacturers may be effectively installed.

3) Last strategy that has been implemented from the CAAP is the freight efficiency. The Ports prioritize competent freight movement to support development without raising or possibly lowering emissions. Efficient operations can save money for both operators and cargo owners by reducing fuel expenses and time spent moving cargo. In 2014, the Ports launched the Supply Chain Optimization (SCO) initiative, bringing along industry representatives to

improve freight productivity. This constant endeavor will contribute to the State's goal of enhancing freight efficiency by 25%, as assessed by trade prize versus greenhouse gas emissions. (Angeles P. o., 2017)

The Port of Los Angeles has proceeded also with the initiative of solar installations. One method the Port is reducing GHG emissions is through the utilization of solar electricity. To date, the Port has deployed about 3 megawatts (MW) of photovoltaic (PV) solar power systems, including those at the World Cruise Center, created at the Port of Los Angeles, and other Port properties.

The Los Angeles Department of Water and Power (LADWP) operates the utility grid through which the PV systems supply clean energy. The Port of Los Angeles has been legally engaged regarding sustainability and environmental concerns with the Ports of Tokyo and Yokohama by signing separate Memorandums of Understanding (MOUs).

The Port of Los Angeles has signed separate Memorandums of Understanding (MOUs) with the Ports of Tokyo and Yokohama to legally engage on sustainability and environmental issues. Throughout the 2023 California-Japan Clean Energy Trade Mission the Port Of Los Angeles authorities proceeded with the signature for the agreements.

The Port of Los Angeles is a member of the **World Ports Climate Action Program**. (Carpenter-Lomax, et al., 2021) The WPCAP contains 12 of the world's biggest ports and has undertaken a number of projects as a result of universal partnerships with ports in Mexico, China, and even the Panama Canal. As the path is already paved these shapes an opportunity to capitalize on the skills and upfront behavior that these players and cooperative activities bring to not just drive the change of one port, but many others in the area and around the world. This has prompted the positioning of considerable justifiable structure, such as shore power stations, electric cargo handling equipment, both electric and fuel cell-powered trucks, and research into the building of the world's first hydrogen-fueled tugboat.

WPCAP ports including the Port of Los Angeles aim to state, protect, sponsor for, and support specific climate action initiatives. Those initiatives are including the practice of sharing knowledge and competent ways with WPCAP members, other ports and involved organizations. The mission of WPCAP and its members is to foster improvement commercial acceptance of low-carbon technology, paving the road for shipping's decarbonization. Developing new regulations and infrastructure for the member ports including shore-power and low carbon marine-fuels. Regulatory bodies and governments can promote low-carbon technology adoption through policies such as tax -policies, incentives and improvement grant. (Carpenter-Lomax, et al., 2021)

Port of Long Beach

The portal of Long Beach is worldwide pioneer in green port projects and has the ability to provide on time services to their clients, moving cargo with dependability, effectiveness and in a short time.

With a value of $200 billion each year the Port of Long Beach is considered as the leading US access across the Pacific Ocean. Additionally, the Port provides a great support to the community with having 2.6 million jobs across the United States, with the biggest portion of work labor concentrated in Southern California. Year of 2022 has been one of the busiest years for the port having dealt 9.13 million twenty-foot equivalent Units. The busy nature of the ports forces the administration of the port to increase effectiveness and move forward with sustainability. The Port of Long Beach is considered as one of the "greenest" ports in the U.S.

Port of Long Beach has been the first port in the U.S that provided a long time ago shore-side electric power to BP oil tankers while on berth in order to avoid having on their diesel engines for a variety of functionalities on the vessel (refrigeration, pumping, lightning etc.).

The Port of Long Beach is as well involved along with the Port of Los Angeles to **San Pedro Bay Ports Clean Air Action Plan** participating in the initiative of Clean Trucks Program (CTP) which was implemented for the first time in 2008, imposed a gradual ban on oldest, diesel drayage trucks which were highly polluting. Since the implementation of CTP in 2012 the emissions arise from port trucks have been minimized more than 90%. The drayage trucks that do exist at the moment at the ports, the majority of them have been equipped with modern engines that are emission-complaint.

During the 2017 Clean Air Action Plan Update, the Port of Long Beach was involved further to the initiatives that will lead to the zero-emission by transitioning terminal equipment to zero emissions until the end of 2030 and on-road trucks by 2035. The California Energy Commission and the California Air Resources Board have granted the Port with $80 million in total in order to move forward with six projects that will support the attempt to zero emission equipment but also the enhancement of innovative energy systems related with Port's operations. (Beach P. O., 2023)

One of the projects granted is related with the transition of the terminal equipment to zero-emissions. The California Energy Commission will provide the funding of $9.7 million, out of the total cost that has been estimated to $13,7 million.

Nine electric rubber-tore gantry cranes, 12-yard tractors and four hybrid and electric drayage vehicles along with the required training programs needed for the development of the handlers/personnel are included as initiatives of this project.

Another initiative that the Port of Long Beach is involved is **the Sustainable Terminals Accelerating Regional Transformation Project (START).** The California Air Resources Board received a $50 million grant to support near-zero and zero-emission supply chains. The START project involves the ports of Oakland and Stockton, providing 100 pieces of zero-emission terminal equipment. The project took place and was led along with terminal operator SSA Terminals LLC, a joint venture between SSA Marine and Matson Navigation Company. Co. (Beach P. o., 2018)

The Port of Long Beach will be equipped from this fund with 33 zero – emissions yard tractors and one zero-emissions top handler at Pier C. This is a prime positioning for this kind of equipment considering we are discussing for a single marine terminal. Additionally, it will provide two container ships with Tier 3 engines, an electric-drive tugboat, five electric trucks at an off-dock container yard and two charging heavy-duty truck outlets.

The Port Advance Vehicle Electrification (PAVE) project at the Port of Long beach is a key endeavor planned at facilitating the conversion to zero-emission cargo-handling equipment. The PAVE project is a $16.8 million endeavor aimed at developing structure for electric-powered, zero-emission cargo handling equipment. One of the milestones of this project is that it contains the first heavy-duty, off-road explicit fast-charging system for battery-powered yard hostlers. The project's goal is to prove the viability and advantages of zero-emission technology in the demanding surroundings of the port. The project will be of major assistance for the implementation of battery storage and energy management technologies to reduce grid effects, and support general final port’s goals for achieving the zero emission cargo handling by 2030 and zero emissions truck operations by 2035.

Left to right (1) main incoming board for the microgrid, (2) wiring for solar PV panel array, (3) microgrid-extending mobile BESS, and (4) 306 kW DC solar PV array on warehouse roof.

Photo Credit: Port of Long Beach

In order to support port’s Joint Command and Control Center, port has recently implemented a **microgrid** in order to provide backup power when needed. The total cost of the microgrid comes to $18 million, from which the $5 million were provided from California Energy Commission and included a solar PV array, fixed BESS and a microgrid – extending the mobile battery energy storage system that is usually linked with port’s microgrid system but is capable to act autonomously and to provide power to other assets, buildings when facing outage.

Port of Long Beach during May 2021 implemented the **Green Ship Incentive Program amendments.** Ships operators are being rewarded for employing the greenest ships to the Port of Long Beach, this plan is effective from July 1, 2021. Since its inception in 2012, the program has assisted the Port enhance air quality by lowering emissions from ocean-going boats. In 2020, members received incentives totaling more than $1.7 million. The Port's adjustment supports the program with global initiatives to promote sustainable maritime transportation. The Port is implementing the International Environmental Ship Index into its program. The ESI is a voluntary index for identifying seagoing ships that surpass the International Maritime Organization's existing emissions regulations. This program involves more than 50 ports around the world and over 8,000 boats. Utilizing the ESI would represent a significant departure from the present program, which only compensates vessel operators for adopting ships with cleaner engines. The Port shall provide economic incentives to operators who have employed cleaner fuels, have proceeded with ship modifications, or have adopted on-board technologies that cut emissions above IMO rules. (Beach P. o., POLB, 2021).

The environmental operation of the vessel is being examined from the ESI program and a score is given based on various factors such as nitrogen and sulfur oxide emissions, carbon efficiency, shore power capability and fuel utilization.

The levels of award that are provided are based on the incentive levels. Each call that has an ESI score 25-47 is qualified to receive $600. Each call with an ESI score of 48-53 is qualified to receive $3000 and lastly each call with an ESI score of 54 or above is qualified to receive $6,000.

Port of Seattle

The Port of Seattle has a strong position concerning the various green initiatives that has planned in order to minimize environmental impact from its activities and encourage sustainability.

Among other initiatives Port of Seattle is officially the opening U.S port to **authorize that every homeported cruise vessel will be shore power capable** and will employ the technology starting from the 2027 cruise season instead of 2030 as predefined. This is a way for ports to secure economic openings and at the same time decrease the environmental impact. It is worth mentioning that this initiative started a long time ago, in 2004 with the investment of Carnival Cooperation, making the Port of Seattle the first port to provide shore power at two cruise berths at the same time. Carnival along with other operators continue those infrastructure investments, having 66% of cruise calls being equipped in order to plug in.

The reduction of the emissions from cruise ships by using shore power is being estimated to be 80% on average. During the 2023 season the shore power technology assisted in escaping 2,700 metric tons of GHG and 0.75 metric tons of diesel particulate matter emissions. The Port is also planning to enhance its collaboration with other ports and the cruise business in order to achieve the establishment of a unique worldwide Green Corridor that will be cruise focused from Seattle to Alaska. The port has also presented a cruise dashboard with data including metrics related with passengers, environment and economy.

Another initiative of the Port is the **restoration of the Ship Supply Building at Fishermen's Terminal**. The renovation aims to create an innovative Maritime Innovation Center (MInC) in order to enable the various stakeholders such as students and academics, public agencies but also citizens of the Seattle to engage with the stability of commercial fishing and maritime industrial activities.

The center will be accredited by the Living Building Challenge (LBC) and will also collaborate with Miller Hull architectural firm in order to successfully create a unique and memorable landmark for the community. The port will provide for this renovation a fund of $100 million, having as a plan to sustain the uniqueness of this historic 1918's building adding sustainable features and materials which will be obtained from local resources.

9. Challenges and Opportunities of ports role in shipping decarbonization

The challenges but also benefits that have been observed from the attempts of ports to address decarbonization are multiple and vary due to the unique infrastructure, policies and systems each port has.

9.1. Challenges

One of the challenges faced is that ports typically prioritize decarbonizing their infrastructure and operations. **There is a paucity of action in areas of user, community and industry influence,** which can have substantial impacts and benefits. Ports often fail to plan for the low-carbon, sustainable economy of the future. Nevertheless, it is imperative that ports develop their sustainability plans taking under consideration the long-run economic health and the long- run commitment to the community. (Arup, 2024). Port sustainability must be considered as a more-extensive idea that includes social (people) and economic (profit) factors.

As globally, ports are operated and administered under various systems of port administration and ownership. There are cases that ports are being under the supervision of the central government that holds all regulatory and landlord powers. There are also ports that are being administrated by a combination of public and commercial service providers.

In some parts of the world the ports' governance model changes radically, with all the regulatory and operational tasks transferred from the public to the private sector, with the ambition of increasing profits with minimal financial effort. Apart from each port's governance structure, the final goal of all ports is to maximize the operational productivity and competence while also improving total direct and indirect economic advantages.

Another challenge that ports decarbonization is facing is that **port governance** is critical in succeeding with the difficulties in decarbonization. Port governance systems are affecting decarbonization programs and the obstacles that may arise. Ports operated by government organizations frequently come across to administrative/ bureaucratic barriers that is possible to impede the implementation of decarbonization measures. On the other hand, with that kind of structure it is easier to use public financing in order to execute large-scale projects. (Forum, 2023).

Particularly in U.S we see two categories of managing ports. There are landlord ports and operational ports. Landlord ports rent out sections of their property to terminal operators, usually stevedoring firms, who oversee activities there in accordance with the conditions of their lease. The equipment that is being used from the terminal operators is often of their own procession. (Pacific Northwest National Laboratory, 2024)

On the other hand, operational ports are in charge for their own activities in the port. Equipment is owned by them, and they usually hire under their supervision dockworkers. In this view, for the landlord ports, the authorities have an indirect role in the decision making when it comes to green initiatives and actions. Landlords usually have to collaborate with their tenants who are usually also the end users. On the other hand, operational ports have a more straightforward control over the equipment and investments to be in place for various actions and strategies. (Pacific Northwest National Laboratory, 2024)

Of course, there are ports that do not fall under either of these categories and do have a more flexible structure.

Financial constraints are considered as one of the most common challenges. Alternative fuels, electrification and the need for green infrastructure require an initial significant funding. There are several smaller ports in the U.S that possibly will not be able to raise the relevant funds for these initiatives. (Arup, 2024)

Grant financing is critical to overcome those financial constraints. In the U.S the Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) have raised several federal funds to exceptional levels. One of them is the Diesel Emissions Reduction Act (DERA) Program that was established by the Energy Policy Act of 2005. This act provided the EPA with new grant and loan power to promote diesel emission reductions, as well as authorization for up to $200 million in annual Agency spending until FY2011. For the first time, congress approved monies for this initiative in fiscal year 2008.

The Port Infrastructure Development Initiative (PIDP) is the second most popular federal initiative for port decarbonization. In addition, Congestion Mitigation Air Quality (CMAQ) and the United States Marine Highways Program (USMHP) are also considered.

Another big challenge is **the low technology readiness and the lack of experience in handling the equipment and facilities while transitioning to zero-emission**. There will be a great demand in highly skilled personnel in maintenance and repair as well as people that will be familiar with automation systems. The right preparation and in time training is likely to reduce the pushback that it is now being observed by the workforce to new technologies and zero-emission equipment due to lack of confidence and proper skills. For instance, the Port of Long Beach works with Long Beach City College and other local educational institutions to progress various training and development programs that adapt the needs of the port industry related to zero-emission technologies, logistics and advanced manufacturing. Although, the Port of Long Beach has the resources to apply the necessary trainings and education to its workforce, state agencies should be also involved and support the smaller ports or more rural ports that wish to provide support to their employees for the zero-emission transition. It is necessary that development programs are identified and implemented for all workforce of ports in order to obtain as much as possible job skill consistency and job flexibility. The low maturity of technologies necessitates greater collaboration among ports, technology providers, and regulatory bodies. Sharing knowledge and best practices can help accelerate the development and adoption of effective decarbonization solutions.

9.2. Opportunities

Despite the challenges faced during the implementation of decarbonization strategies from ports there are also new opportunities.

Key opportunity that arises from the ports decarbonization is the **environmental benefits.** Through the replacement of fossil-fuel powered equipment, onshore power supply, vessel's berth optimization, alternative fuels bunkering and other initiatives, ports are able to significantly minimize gas emissions, curb air, water pollution, noise pollution and provide a better and more sustainable environment for port workers but also the communities existing around the port.

Measures and “green” strategies are providing cleaner air around ports by minimizing the emissions of harmful pollutants. It is known that communities and citizens living around ports are often more vulnerable to respiratory and cardiovascular diseases, lung cancer and premature mortality. Moving forward actions that will minimize GHG emissions will also reduce dangerous impacts of port operations.

Another **opportunity for ports is to develop a better collaboration with the communities surrounds them**. The energy transition puts pressure on the governments in order to enhance the relationships between city and port. Development schemes based on a fully oil-based economy, along with the international growth in shipping container transit in the second part of the twentieth century, isolated city and port at all levels. Ports were relocated from metropolitan areas due to a lack of space, with massive industrial port zones established on the city's outskirts.

Pollution has prompted citizens in port cities to act. Local environmentalism has pushed ports to become more accessible to cities by encouraging the growth of circular economy and industrial technology. Many ports have started energy transition programs to improve city-port ties. The port region is proving to be a good location for testing out new methods based on increased collaboration among local actors.

Ports are also having the opportunity for new collaborations, by dealing with regulatory bodies, local industry, terminal operators and a variety of important stakeholders.

These changes will present new opportunities for ports to collaborate with local industry, businesses and community groups. For example, as the city moves towards ambitious decarbonization targets, the Port of Oslo has linked up with a local waste to power facility to use their biogas waste and excess heat. Copenhagen Malmo Port is working with the local municipality and utility company to develop a power storage that can also be used by the city.

Ports with the enforcement of a more sustainable future can also concur **resiliency.** Resiliency for the ports is a great opportunity especially due to their complex environment. The ability to prepare for and familiarize to altering conditions and resist and recover rapidly from accidents, mishandling or naturally occurring incidents will help tremendously ports to improve their operation ability in the long term. Ports can become more resilient trough innovation to essential infrastructure. Ports that will invest to microgrid systems, digitalization and use of cloud or terminal automation and operation system have advanced resiliency towards power outages and disruptions and also minimize the mistakes originated from human factor. These systems are providing great support and ensuring that key operations can be fully executed even while facing difficult conditions.

Another important element to consider is that ports by functioning through electrification or hybridization are securing extra energy independence. Ports that are engaging and finance on-site energy generation are being able to have an expanded energy mix that is well equipped to resist in case of unpredictable events.

10. Conclusions

This thesis explored the existing trends in regulations for decarbonization of shipping presenting the regulatory timeframe but also a brief mention to some of the existing alternative fuels and the challenges that are in place throughout their implementation. Academic literature, technical and business reports and websites have been reviewed in this thesis. There is no single route to fully decarbonize the maritime industry so a multifaced response is required.

This thesis explored the literature to also create a frame around the port's role in decarbonization. The study presented the portside, ship-port interface and land transport measures and in general the operation schemes for reducing GHG emissions in the shipping sector with port's support.

The presence of U.S ports has been defined within this thesis, exploring the initiatives that have been undertaken so far from three major ports of the area. U.S ports are key national infrastructures and safeguarding their sustainable actions and operations is of great importance for the global and regional trade. The several measures that have been already implemented or are subject to implementation and future consideration are leading solutions in order to minimize the unsafe environmental and human health impacts of fossil-fueled port operations.

The various innovative actions and technologies that are considered and suggested in order to ensure sustainable operations may burden ports with additional costs and probably the transactional period will not be easy due to the complexity of ports infrastructure and governance that exists. Nevertheless, moving forward and establishing a sustainable planning and sustainable measures and actions is essential in order to achieve the targets for zero emission in maritime industry but also provide a sustainable and healthy environment for the communities in the long run. A complex multi-stakeholder effort is required following proper arrangements from all the key stakeholders included (tenants, customers, employees, community organizations, labor representatives and equipment providers) in order to achieve long-term sustainable development.

Bibliography

Alamoush A.S, Ballini F., Aykut I.O (2020) Ports' technical and operational measures to reduce greenhouse gas emission, available: https://doi.org/10.1016/j.marpolbul.2020.111508

Martín-Soberón A.M, Monfort A., Sapiña R., Monterde N., Calduch D., (2014) Automation in port container terminals, available: https://doi.org/10.1016/j.sbspro.2014.12.131

Sorrell S., O'Malley E., Schleich J., Scott S., (2004). The Economics of Energy Efficiency: Barriers to Cost-Effective Investment

Styhre L., Winnes H., Black J, Jimyoung L., Le-Griffin. H.,(2017) Greenhouse gas emissions from ships in postudies in four continents available : https://doi.org/10.1016/j.trd.2017.04.033

United States Environmental Protection Agency (2024), available: https://www.epa.gov/ports-initiative/cleanports

Acciaro M., Hoffmann P.N., The energy efficiency gap in maritime transport (2013), available: https://www.researchgate.net/publication/281315278_The_energy_efficiency_gap_in_maritime_transport

United States Environmental Protection Agency U. S. (2023), Ports Primer: 7.3 Federal Environmental Regulations and Programs, available: https://www.epa.gov/community-port-collaboration/ports-primer-73-federal-environmental-regulations-and-programs#cwa [accessed 10 October 2024]

San Pedro Bay Ports Clean Air Action Plan 2017 Port of Long Beach and Port of Los Angeles ,available: https://kentico.portoflosangeles.org/getmedia/9d371f7b-9812-4c75-bcfd-23e83a191435/CAAP_2017_Draft_Document-Final

Port of Los Angeles–Port of Shanghai Green Shipping Corridor Partnership Implementation Plan Outline, 2023, available: https://www.portoflosangeles.org/

Environmental Defense Fund and Arup, (2024), Practical Pathways For Port Decarbonization And Environmental Justice, available: https://www.edf.org/sites/default/files/documents/2024-EDF_Port_Decarb_EJ_Report_0.pdf

Port of Long Beach (2018) Sustainable Terminals Accelerating Regional Transformation, available: https://buildmomentum.io/project/port-of-long-beach-sustainable-terminals-accelerating-regional-transformation-start-phase-1

California Air Resources Board, (2020), Ocean Going Vessels At Berth Regulatory Documents, available://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/ocean-going-vessels-berth-regulatory

California Air Resources Board, (2022), Retrieved from Final Regulation Order Commercial Harbor Craft Regulation available: https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-regulatory-documents

Calderón M., Illing D., Veiga J., Facilities for bunkering of liquefied natural gas in ports (2016), available: doi: 10.1016/j.trpro.2016.05.288

CARB approves updated “At-Berth” regulation, expanding efforts to cut pollution from ships in California ports. (2020, August 28). Retrieved from Green Car Congress: https://www.greencarcongress.com/2020/08/20200828-carb.html

Carpenter-Lomax, O., Wilkinson, G., Martinez, V. and Georgiev, M, ‘Zero-Carbon for Shipping; Sailing carbon-free along North America’s west coast’, Ocean Conservancy, Washington D.C., 2021

Maersk Mc- Kinney Moller Center (2002), Maritime Decarbonization Strategy, available: https://www.zerocarbonshipping.com/publications/maritime-decarbonization-strategy/

ClassNK. (September 2024), ClassNK Alternative Fuels Insight, available: https://download.classnk.or.jp/documents/ClassNKAlternativeFuelsInsight_e.pdf

Critchfield, J. (2019), Understanding the Impact of the California Truck and Bus Regulation, Weber Logistics, available: https://www.weberlogistics.com/blog/california-logistics-blog/understanding-california-truck-and-bus-regulation

Economic Forum, (2023), Fueling the Future of Shipping: Key Barriers to Scaling Zero-Emission Fuel Supply World, available: WEF_Fuelling_the_Future_of_Shipping_2023.pdf

Goldman School, University of California, Berkeley , (2024), Policy Options to Decarbonize Ocean-Going Vessels, available: https://www.pacificenvironment.org/wp-content/uploads/2024/05/Policy-Options-to-Decarbonize-Ocean-Going-Vessels-REPORT_FinalReview.pdf

Raucci C., McKinlay C., Karan A., (2023), Lloyds Register Decarbonization Hub, The Future of Maritime Fuels

IMO. (2024, March 22). IMO agrees possible outline for maritime "Net-zero framework. Available: https://www.imo.org/en/MediaCentre/PressBriefings/pages/IMO-agrees-possible-outline-for-net-zero-framework.aspx

Byongug Jeong, M. K. (07 December 2022). Decarbonization Trend in International Shipping Sector. Journal of International Maritime Safety, Environmental Affairs, and Shippi*ng*

Pierre J., Jain P. , Jan Matthé H.,(2022), Exploring how hydrogen and hydrogen hubs at ports can advance the global transition from fossil fuels to clean energy,

Khan L., Macklin J R, Peck B C D, Morton O, Souppez J-B R G, (2021), A review of Wind - Assisted Ships Propulsion for Sustainable Commercial Shipping: Latest Developments and Future Stakes, Wind Propulsion Conference

Zhang L., Zeng Q, Wang L., (2024), How to Achieve Comprehensive Carbon Emission Reduction in Ports? A systematic Review, Journal of Marine Science and Engineering

Lloyd's List (2024), Decarbonization, available: https://www.lloydslist.com/Special-report-decarbonisation

Mallouppas G., Yfantis E. Ar., (2021), Decarbonization in Shipping Industry: A Review of Research, Technology Development, and Innovation Proposals, Journal of Marine Science and Engineering, available: https://doi.org/10.3390/jmse9040415

Bakar N.N. A, Bazmohammadi N., Vasquez J.C., Guerrero J.M., (2023) , Electrification of onshore power systems in maritime transportation towards decarbonization of ports: A review of the cold ironing technology, Renewable and Sustainable Energy Reviews, available : https://doi.org/10.1016/j.rser.2023.113243

Pacific Northwest National Laboratory, (2024), Port Electrification Book: A Reference to Aid to U.S Port Energy Transitions, available : Port Electrification Handbook | PNNL

Prevljak N.D., (2024), IMO MEPC 81: The clock is ticking for fossil fuel era in shipping, Offshore Energy, available: https://www.offshore-energy.biz/imo-mepc-81-the-clock-is-ticking-for-fossil-fuel-era-in-shipping/

Changwook K., Sangick L., Korean Register (2023), Methanol as a Marine Fuel

Lloyd's Register ,Fuel For Thought: Biofuel (2024), available: https://www.lr.org/en/knowledge/research-reports/2024/fuel-for-thought-biofuel-report/

Robinson, A. (2023), The Clean Shipping Act of 2023: Here's What You Need to Know, GreenABL, available: https://greenabl.co/the-clean-shipping-act-of-2023-heres-what-you-need-to-know/

Todd Chou, Kosmas V., Acciaro M., Renken K., (2021). A Comeback of Wind Power in Shipping: An Economic and Operational Review on the Wind-Assisted Ship Propulsion Technology, available: https://doi.org/10.3390/su13041880

Wang B., Liu Q., Wang L.,Chen Y., WangJ.,(2023),available : https://doi.org/10.1016/j.envpol.2023.121000