Ports' Approaches to Reducing Greenhouse Gas Emissions: A Case Study of The Northwest Seaport Alliance

Murat Polat

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Nives Dolšak, Chair

David Fluharty

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Abstract

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Murat Polat

Chair of the Supervisory Committee:
Dr. Nives Dolšak
School of Marine and Environmental Affairs

Today, marine transportation substantially contributes to the global economy by carrying approximately 90% of the goods worldwide. It is also one of the fastest-growing sectors in terms of greenhouse gas (GHG) emissions. The main polluters of the industry are shipping vessels, but the transboundary nature of the shipping operations makes it challenging to regulate related GHG emissions. As a key node of maritime operations, ports' potential to mitigate GHG emission has gained increased attention from the general public in the last decades, but global regulations remain absent. Therefore, ports address local, state, and federal social and regulatory pressures while adapting to the rapid changes in the industry. To explain the factors influencing ports' approaches to reducing GHG emissions, we conducted a descriptive case study of the

Northwest Seaport Alliance (NWSA) based on publicly available documents. We found that carbon intensity of the port electricity, availability of external funding, possible cargo diversion due to the imposed environmental standards, the existence of regulatory support, GHG emissions related developments in regions where competitor ports are located, and utilization of the concession agreement with the port users are the primary factors that affect the NWSA's GHG reduction approaches.

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ABBREVIATIONS

BCOs	Beneficial Cargo Owners
CAAP	California Air Action Plan
CARB	California Air Resource Board
CDFI	Community Development Financial Institution
CH4	Methane
CHE	Cargo Handling Equipment
CII	Carbon Intensity Index
CIP	Capital Investment Plan
CMAQ	Congestion Mitigation and Air Quality
CO2	Carbon dioxide
CTF	Clean Truck Fund

CTP	Clean Truck Program
DCS	Data Collection System
DERA	Diesel Emission Reduction Act
DPF	Diesel Particulate Filter
DWT	Deadweight
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Design Index
EMP	Energy Management Plan
EPA	Environment Protection Agency
ESSs	Energy Storage Systems
EU	European Union
EU ETS	European Union Emission Trading System
EU MRV	European Union Monitoring, Reporting and Verification
FEIS	Final Environmental Statement
FOC	Flag of Convenience
GHG	Greenhouse Gas
GOS	Gate Operating System
GT	Gross Tonnage
GVC	Global Value Chain
HMT	Harbor Maintenance Tax
IMO	International Maritime Organization
LED	Light-emitting diode
LNG	Liquefied Natural Gas
LOCS	Law of the Sea
MARPOL	International Convention for the Prevention of Pollution from Ships
MOU	Memorandum of Understanding
MPEC	Marine Environment Protection Committee
MUP	Master Use Permit
N2O	Dinitrogen Monoxide
NGO	Non-governmental Organization
NOx	Nitric Oxide
NWPCAS	Northwest Ports Clean Air Strategy

NWSA	Northwest Seaport Alliance
OPS	On-shore Power Supply
PCT	Pierce County Terminal
PIPD	Port Infrastructure Development Program
PM2.5, PM10	Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
POS	Port of Seattle
POT	Port of Tacoma
PSCAA	Puget Sound Clean Air Agency
PSRC	Puget Sound Regional Council
PV	Photovoltaic Cells
RAISE	Rebuilding American Ifrastructure with Sustainability and Equity
RFID	Radio Frequency Identification System
RMS	Rail Management Services
RTG	Rubber-Tired Gantry
SCAQMD	South California Air Quality Management District
ScRAPS	Seaport Truck Scrappage and Replacement for Air in Puget Sound
SDCI	Seattle Department of Construction and Inspection
SDOT	Seattle Department of Transportation
SEEMP	Ship Energy Efficiency Management Plan
SLM	Smart Load Management
SOx	Sulfur Oxides
STD	Open Standard Passifve RFID
SWH	Solar Water Heating
TOS	Terminal Operating System
TransAlta	TransAlta Centralia Coal Transition Grant Program
ULSF	Ultra Low Sulfur Fuel
UNFCCC	United Nations Framework Convention on Climate Change
USDOT	United State Department of Transportation
VOC	Volatile Organic Compounds
VW Grant	Volkswagen Mitigation Settlement

WPCI	World Port Climate Initiative
WSDOT	Washington State Department of Transportation
WTA	Washington Trucking Association
WUT	Washington United Terminal

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Chapter 1. INTRODUCTION

The combination of containerization, larger vessel size, and growing port trading volume with the ocean-borne commerce’s comparative advantages of economies of scale and network economies resulted in lower transportation costs for the shipping industry in the last decades (Hossain, 2020; Zheng et al., 2020). Today, international shipping is a vital part of the global economy consisting of 55,100 large cargo ships that carry 11 billion tonnes of goods every year, which make up about 90% of global trade (Alamoush et al., 2022; Maragkogianni et al., 2016a; Primorac, 2018; Zanne & Twrdy, 2021; Zheng et al., 2020). The maritime industry is anticipated to grow with an average annual 3.5% growth rate over the next years and to account for the transportation of 23 billion tonnes of freight in 2060 (Maragkogianni et al., 2016a; Zheng et al., 2020).

1.1 General Overview of International shipping emissions

Although marine transportation is an efficient and environmentally friendly way of transporting goods due to its low emissions per unit of transported cargo, it is a polluting industry in terms of local air pollution and GHG emissions (Alamoush et al., 2022; Primorac, 2018). The maritime industry is responsible for producing high levels of harmful air pollutants, such as Nitrogen Oxides (NOx), Sulphur Oxides (SOx), Carbon Monoxide (CO), Volatile Organic Compounds (VOC), and particulate matter (PM2.5, PM10) (Dai et al., 2019; Gössling et al., 2021). These emissions degrade not only surrounding environmental quality but also are harmful to people's health, especially NOx and PM2.5, which can have a critical health impact on people living in coastal areas (Giuliano, 2013; Maragkogianni et al., 2016a; Poulsen et al., 2016; Radwan et al., 2019). Densely populated port cities are more unprotected from those emissions, which makes the port’s adverse impact on the environment more visible and attracts more attention from the public (Dai et al., 2019; Gössling et al., 2021; Poulsen et al., 2018).

Global warming potential emissions from shipping activities are mainly carbon dioxide (CO2), methane (CH4), dinitrogen oxide (N2O), and black carbon (Winnes et al., 2015). According to the International Maritime Organization (IMO)'s fourth GHG study, the maritime industry is responsible for 2.89% of total global GHG emissions, which was increased by 9.6% between 2012 (977 Mt CO2-equivalent) and 2018 (1076 Mt CO2-equivalent) (Alamoush et al., 2022; Godet et al., 2021; Gössling et al., 2021). If the maritime industry was a country, it would be the sixth-largest GHG emitter nation in the world (Alamoush et al., 2022; Maragkogianni et al., 2016a). Shipping CO2 emissions approximately doubled between 1971 and 2019; moreover, studies that were carried out based on business-as-usual scenarios show that the total shipping GHG emissions will rise by 90-130% relative to the 2008 level and 0-50% relative to the 2018 level by 2050 meaning that shipping emissions could represent more than 10% of global emissions in the year of 2050 (Alamoush et al., 2022; Gössling et al., 2021; Nunes et al., 2019). Therefore, fulfilling the shipping industry's own responsibility to keep the average global temperature below 2°C is getting more difficult if dramatic changes are not taken, such as the replacement of fossil fuels with renewable fuels (Styhre et al., 2017; Winnes et al., 2015).

Regulating the environmental impact of the maritime industry is difficult due to its unique nature, worldwide operations that are carried out with vessels registered in various countries sailing on different regions enforcing different regulations (Shi, 2016; Maragkogianni et al., 2016a; Tanaka, 2016). As a specialized agency of the United Nations, the IMO is responsible for regulating safety, navigational efficiency, and pollution prevention issues for the international shipping industry (Maragkogianni et al., 2016a; Tanaka, 2016). To protect the ocean and atmosphere from shipping pollution, The Marine Environment Pollution Committee (MPEC), a sub-organization of the IMO, carries out the preparation and implementation of the environmental regulations (Shi, 2016; Maragkogianni et al., 2016a; Tanaka, 2016). In terms of mitigating the adverse impact of the shipping industry on global climate change, in 2018, the IMO kicked off its Initial GHG Strategy to align shipping emissions with the Paris Agreement, aiming to reduce total GHG emission from international shipping by 50% by 2050 relative to the 2008 level (Alamoush et al., 2021, 2022). There is also a carbon intensity target, meaning that carbon emission per transported unit should be reduced by 40% by 2030 and then by 70% by 2050 compared to the 2008 level (Alamoush et al., 2021, 2022; Godet et al., 2021). In consideration of the annual growth of the international shipping industry, designated GHG targets are becoming more ambitious and require prompt and effective measures to take place (Godet et al., 2021).

1.2 General Overview of Port emissions

Seaports are essential gateways for international shipping by being key nodes of the global supply chain and marine transportation network (Hossain, 2020; Zheng et al., 2020; Zis, 2015). Ports consist of one or more terminals and are required to meet three main conditions to provide sufficient traffic (Zis, 2015). Port terminals should have a safe and accessible entrance from the sea; sufficient hinterland connection through road, rail, or inland waterways; and adequate cargo handling equipment, space for storage of cargo, ship maneuvering, and berthing (Zis, 2015). Besides cargo transportation, ports also provide value-adding services for marine transportation, such as warehousing, packing, maintenance, shipbuilding, and bunkering (Zheng et al., 2020; Zis, 2015). Ports are classified as public and private ports based on their ownership, and public ports are categorized into three main types: landlord ports, service ports, and tool ports (Zis, 2015). Ports are generally governed by port authorities that are responsible for construction projects, administration, operation of port facilities, and security (Zis, 2015). Ports can contain different types of terminals, such as container, Ro-Ro, liquid bulk, dry bulk, ferry, and multi-purpose terminals (Zis, 2015). Terminals consist of various components, including wet and dry infrastructures, superstructures, cargo handling equipment, and human resources (Zis, 2015). The wet infrastructures are called berths where the vessel and terminal contact occurs (Zis, 2015). The dry infrastructures are cargo storage areas, terminal roads, crane track foundations, and drainage systems (Zis, 2015). The superstructure is comprised of the main building, sheds, and storage facilities. The cargo handling equipment and human resource type and size differ based on terminal type and size (Zis, 2015).

Ports create demand for transportation activities within their region and stimulate local and regional economic growth while generating direct and indirect jobs for local communities (Hossain, 2020; Zanne & Twrdy, 2021; Zheng et al., 2020; Zis, 2015). Moreover, ports link marine and inland transportation; and along with their ability to influence end-to-end transportation emissions that occur at sea, within port boundaries, and within port hinterland; ports play a key role in the sustainable development of the port city's entire urban network (Fenton, 2017; Sornn-Friese, 2021; Zheng et al., 2020). On the contrary, port activities have an adverse impact on the environment (Alamoush et al., 2020, 2021, 2022; Hossain, 2020; Lam & Li, 2019; Zheng et al., 2020; Zis, 2015), including air pollution, water quality degradation, soil contamination, waste production, habitat destruction, biodiversity loss, traffic congestion, land use impact, odor, and dust (Zanne & Twrdy, 2021; Zheng et al., 2020; Zis, 2015). Ports activities involve shipping traffic, intermodal transportation, and internal activities as a transportation hub and host a high level of marine transportation emissions imperatively (Alamoush et al., 2020; Hossain, 2020). Main emission sources within port areas are ships, rail systems, trucks, and cargo handling equipment emitting various air pollutants, such as GHG, especially carbon dioxide, NOx, SOx, and particulate matter (PM) (Sornn-Friese, 2021). Since shipping operations within port areas, including hoteling at anchorage, hoteling at berth, and maneuvering are highly fuel-inefficient, in developed countries, shipping activities account for 70-100% of total emissions within 400km of land, and 60-90% of those shipping emissions occur while ships are at berth position (Dai et al., 2019; Lam & Li, 2019; Sifakis & Tsoutsos, 2021; Zheng et al., 2020) Rail and road transportation emissions make up one-fifth of what ships generate and infrastructural emissions, accounting for 15% of total emissions from port activities (Sifakis & Tsoutsos, 2021). Therefore, along with the high portion of shipping emissions within port domains, port authorities have an opportunity to influence not only emissions caused by their own facilities and operations but also shipping and hinterland transportation activities which resulted in an increased significance of port authorities' role over shipping companies in maritime sustainability (Alamoush et al., 2020; Lam & Li, 2019).

In the last decades, ports have faced dramatic transformations derived from technological developments, commercial changes, and environmental issues (Martínez-Moya et al., 2019). Port authorities are required to adopt stricter environmental regulations at both regional and international levels and protect communities near ports from the external negative impact of the port activities (Martínez-Moya et al., 2019; Sornn-Friese, 2021). In addition, port activities' negative impact on the environment rises along with the growing cargo throughput handled, so ports' environmental performance has gained increasing attention (Alamoush et al., 2020; Sornn-Friese, 2021; Xu et al., 2021; Zheng et al., 2020; Zis, 2015). Therefore, ports are under increasing social and institutional pressure from regulators, cargo owners, shippers, port users, local communities, and NGOs (Alamoush et al., 2020; Martínez-Moya et al., 2019; Sornn-Friese, 2021; Zheng et al., 2020), and need to address their concerns to secure their social license to operate

(Sornn-Friese, 2021). Traditionally, ports have focused on NOx, SOx, and PM emissions rather than GHG emission because of SOx, NOx, and PM emissions' visible contribution to the local air pollution and adverse impact on human health, especially for ports located near dense populations (Poulsen et al., 2018; Sornn-Friese, 2021; Winnes et al., 2015). In addition to that, the exclusion of shipping emission from the Kyoto Protocol, maritime transportation's environmentally friendly image, and the importance of the growth of global trade caused the delay in addressing the port activities' contribution to global climate change (Winnes et al., 2015).

However, along with the global communities ascending awareness of global climate change and their recognition of the need for urgent global action to reduce GHG emissions from all industries, ports' contribution to global climate change has become one of the most important topics in the maritime industry and the port's potential to influence GHG emission from the supply chain has received increased attention from academia, research groups, NGOs and tech companies (Dai et al., 2019; Davarzani et al., 2016; Sornn-Friese, 2021; Zheng et al., 2020). The apparent primary reason for cutting GHG emissions efforts is to mitigate port activities' contribution to global climate change and take advantage of common benefits from a sustainable future (Hossain, 2020; Styhre et al., 2017; Winnes et al., 2015). Technological factors are generally the availability of new and energy-efficient technologies that improve ports' throughput handled and reduce energy emission costs (Styhre et al., 2017; Winnes et al., 2015). Economic drivers are potential marketing opportunities for proactive green ports and reducing energy costs (Lam & Li, 2019; Sornn-Friese, 2021; Styhre et al., 2017; Winnes et al., 2015; Xu et al., 2021). Legal factors are national and regional regulations, such as California Air Resource Board (CARB) and European Union (EU) regulations (Alamoush et al., 2020; Giuliano, 2013; Zis, 2015). Political factors that drive port authorities to tackle GHG emissions are improving port's social legitimacy, maintaining a social license to operate by responding to public pressure from local communities and NGOs, and elevating the port's green reputation to attract customers seeking to greener its supply chain (Giuliano, 2013; Hossain, 2020; Linder, 2018; Sornn-Friese, 2021). Today, the environmental performance of the port is considered an important indicator of the port's overall quality by the general public, cargo owners, shipping companies, municipal networks, and regulatory agencies (Fenton, 2017; Hansen & Steen, 2021; Xu et al., 2021). Accordingly, the port industry has come up with the green port concept, meaning that a sustainable port maintains economic growth, environmental protection, and social wellbeing simultaneously (Azarkamand et al., 2020; Sornn-Friese, 2021; Tsai et al., 2018; Zanne & Twrdy, 2021).

Total global GHG emissions from port activities have not been calculated yet since ports conduct different emission inventory methodologies consisting of different scopes, outreach, calculation methods, and cargo definitions (Alamoush et al., 2021). Recent studies show that GHG emissions generated from ports' own operations, including buildings, waste management, personal commuting, and administration, are equal to 5 to 15% of shipping emissions and half of the GHG emissions generated by hinterland transportation (Alamoush et al., 2021; Radwan et al., 2019; Styhre et al., 2017; Zheng et al., 2020). Therefore port authorities are required to focus on reducing GHG emissions from both port facilities under their control, and shipping and hinterland operations which they have limited capability to influence due to legal, economic, and political complexity and physical limitations since shipping, road, and rail transportation are highly fossil fuel-dependent industries (Alamoush et al., 2020, 2021, 2022; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021). Despite their limited influence capacity, port authorities can effectively influence GHG emissions from shipping and hinterland transportation by providing infrastructures, such as the supply of alternative fuel and on-shore power, and implementing incentive programs, such as vessel speed reduction programs and environmentally differentiated port dues for vessels (Alamoush et al., 2022; Bjerkan & Seter, 2019a).

However, since the GHG emissions from port activities have not been regulated globally, and there is no one-size-fits-all measure to reduce port-related GHG emissions, port authorities need to implement the most cost-effective measures and incentives that fit their operation, businesses, geography, terminal size and type, customer profile, economic situation, competitiveness, and that address pressure from the environmental concerns of the general public and regulatory agencies (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Sornn-Friese, 2021). This unforeseen situation experienced by ports results in long-term stress on port strategies and affects port infrastructural development negatively (Sifakis & Tsoutsos, 2021). Nevertheless, some major ports have achieved substantial emission reduction and local air quality improvements by implementing a combination of complex emission abatement measures that required the wide-scale collaboration of port stakeholders (Ashrafi et al., 2020; Castellano et al., 2020; Hall, 2013; Lam & Li, 2019).

Chapter 2. THE NORTHWEST SEAPORT ALLIANCE

The Northwest Seaport Alliance (NWSA) is a marine cargo operating partnership of the largest ports in Washington State; Port of Seattle (POS or north harbor) and Port of Tacoma (POT or south harbor) (The Northwest Seaport Alliance [NWSA], 2017a). It was established in August 2015 to respond to the dramatic changes in the maritime industry and enhance the Puget Sound gateway and attract additional business to the area (NWSA, 2017a). The two homeports' marine cargo terminal investments, operations, planning, and marketing efforts are integrated under Port Development Authority (PDA) (NWSA, 2017a). Each port is represented in PDA by an equal number of commissioners elected by King and Pierce County citizens. The commissioners' service time is limited to four years (NWSA, 2017a). By unifying their forces in a partnership, the two ports aimed to eliminate pricing competition and strengthen the Salish Sea’s gateway competitiveness among West Coast ports. The need to increase competitiveness was especially acute after east coast ports began to step into Asia-Pacific trade with the widening of the Panama Canal (NWSA, 2021a). Moreover, the NWSA homeports take advantage of the consolidation of power by strengthening investment capacity, diversifying and improving quality of service, and increasing political power at local, state, and federal levels (NWSA, 2021a).

The NWSA is the first of its kind and fourth-largest container gateway in North America (NWSA, 2017a). It links marine cargo from Asia to the major distribution locations in the Midwest, Ohio Valley, and the East Coast and provides various services in the Asia-Pacific trade and Alaska region (NWSA, 2017a). It contributes $12,4 billion to the state economy and $136 million in state taxes annually while generating 58,400 jobs (NWSA, 2021a). In 2019, the port held $74.9 billion in two-way cargo trade and $26,9 billion of those carried out with the prime partner of the Alliance, the country of China (NWSA, 2020a). The trade volume of the homeports included in NWSA increased gradually between 2013 and 2018 went from 3.5 million TEUs (twenty-foot equivalent units) to 3.8 million TEUs (NWSA, 2018a, 2019). The cargo volume decreased slightly to 3.78 million TEUs in 2019. The gateway experienced a sharp fall in trade volume in 2020, declining to 3.32 million TEUs because the NWSA was greatly affected by the trade constraints caused by the global coronavirus pandemic (NWSA, 2020a, 2021a). Thirty percent of the total trade consisted of domestic cargo, meaning that more than 70 percent of the transporting cargo was either destined or originated in global routes (NWSA, 2018a, 2019, 2020a, 2021a). There was a rise in the cargo volume between 2013 and 2018, but the number of vessel calls decreased slowly between 2013 and 2020, which accounted for 2,227 and 1684, respectively (NWSA, 2018a, 2019, 2020a, 2021a).

The NWSA competes for Asia-Pacific trade. Its primary trade partners by cargo volume are Asia-Pacific countries, including China, Japan, Vietnam, Taiwan, South Korea on the import side, and Japan, South Korea, China, Taiwan, and Indonesia on the export side (NWSA, 2018a, 2019, 2020a, 2021a). In 2017, China took first place on both imports and exports operations with 832,890 TEUs and 219,106 TEUs, respectively; however, it lost its number one position on the export side to Japan and took third place in 2020 with 127,161 TEUs (NWSA, 2018a, 2021a). Although China lost its first position in cargo volume, it remains the leading trade partner of the NWSA for both imports and exports when the cargo value is taken into consideration (NWSA, 2018a, 2019, 2020a, 2021a).

The NWSA was established partially in response to changes in the shipping industry. Only a decade ago, the average vessel volume was 4,000 TEUs, less than half of what it accounts for today (NWSA, 2017a). The top nine container shipping companies in the world have ordered 86 new vessels with more than 10,000 TEUs capacity, meaning that 1.47 million TEUs are expected to be delivered by 2024 (NWSA, 2021a). Therefore, the NWSA's capability to accommodate ultra-large vessels is essential to compete in Asia-Pacific trade. Pier 4 modernization project at Husky Terminal in the south harbor and Terminal 5 modernization project in the north harbor was designed as "big ship ready," They will allow the gateway hosting vessel to call up to 18,000 TEUs (NWSA, 2017a). The port projects that modernized Terminal 5 by itself will deliver 1.6 million TEUs of 7 million TEUs that are expected to transit through both homeports in the year 2050 (NWSA, 2019).

However, modernization of terminals is not enough to host ultra-large container vessels. Federal channels that serve ports' marine terminals need to be deepened (NWSA, 2019). The NWSA committed to working together with U.S. Army Corps and Engineers in deepening projects. Blair Waterway will be deepened in the south harbor, and West Waterway and Duwamish River's deepening effort will be completed in 2024, aligned with Terminal 5's completion in the north harbor (NWSA, 2019). The larger vessel trend is not the only influencing driver in the industry that shapes port investment decisions and operation models. Another essential sector force is strategic alliance formation in container shipping companies (NWSA, 2021a). The three major alliances (2M, Ocean Alliance, and The Alliance) hold three-quarters of the global market with an estimated 16 million TEUs (NWSA, 2018a). Thus, offering compatible services to these major alliances' is crucial for ports' survival. The NWSA adopted the service-centered approach to provide adequate service to its customers (NWSA, 2018a).

Ninety percent of the PM and GHG emissions are linked with sea transportation in the Seattle-Tacoma Airshed (NWSA, 2021i). Therefore, the major ports located in the Puget Sound-Georgia Basin airshed voluntarily adopted the Northwest Ports Clean Air Strategy (NWPCAS) to not experience similar pressures due to the negative impact of their operations on air quality (Port of Seattle, 2009).

The NWPCAS was developed in December 2007 as of voluntary effort of the three largest ports located in Puget Sound: Port of Seattle, Port of Vancouver to mitigate port-related greenhouse gas (GHG) and diesel emissions in Puget Sound - Georgia Basin (Port of Seattle [POS], 2009). The primary objectives of the strategy are to reduce maritime transportation-related air emissions that have an adverse impact on human health, environment, and economy, global climate change, and keep the Puget Sound region in compliance with the air quality standards (POS, 2009). The plan was designed to achieve early emission reductions to mitigate the pressure of pending regulations and even go beyond. The strategy's success highly relies on the proactive engagement of diverse port stakeholders, including participating ports, shipping companies, terminal operators, trucking companies, rail operators, industry partners, regulatory agencies, and local communities. (POS, 2009). The strategy’s operational scope involves six main polluters: ocean-going vessels, cargo handling equipment (CHE), rail, trucks, harbor vessels, and port administration (POS, 2009).

Between 2008 and 2010, IMO’s North American Emission Control Areas (ECA) were not enacted yet, therefore, and the initial measures adopted for port sectors were aimed to reduce local air pollution, including tracking low sulfur fuel usage in OGVs, enacting EPA emission standards for CHE and trucking sectors (POS, 2012). After the adoption of the ECA regulations in 2012, setting the maximum sulfur content in fuel to 1% from 2012 and then %0.1 from 2015 (POS, 2012), SOx emissions from port operations decreased substantially, and the participating ports shifted their focus on reducing PM and GHG emissions (POS, 2014). Along with the NWPCAS 2013 update, the EPA’s stricter emission standards imposed on CHE and trucking and significant reductions in NOx and DP emissions were observed in the 2016 Puget Sound Maritime Air Emission Inventory (PSEI) (NWSA, 2021i).

In 2013, the GHG emissions were included in the NWPCAS for the first time. The GHG reduction target was demonstrated as reducing GHG emissions per ton of transported freight by 10% by 2015 and 15% by 2020 (POS, 2014), along with the inclusion of practical measures, such as alternative fuels and OPS (POS, 2014). Besides GHG, PM target was determined as mitigating PM emissions per top of cargo by %75 by 2015 and %80 by 2020 (POS, 2014). Another significant development for the ocean-going vessel section in 2013 was that ports began to offer third-party efficiency improvement programs to shipping companies (POS, 2014). The truck measure was improved from %80 to %100 percent of all trucks are required to have 2007 or newer model engines by 2017 (Port of Seattle, 2014). In addition, new harbor vessel and port administration standards were identified within the 2013 NWPCAS update (POS, 2014). Lastly, new emission reduction measures were demonstrated for the rail system, harbor crafts, and port administration sectors in the 2013 NWPCAS update (POS, 2014).

According to the 2016 Puget Sound Clean Air Agency emission inventory, the strategy met its 2020 DPM and GHG targets four years early, by the end of 2016, by reducing DPM by 80% and GHG by 17% per ton of cargo relative to the 2005 level (NWSA, 2020a). In 2017, the NWSA launched its 2017 GHG Resolution, which aligned the NWSA's GHG targets with port stakeholder targets, including the City of Seattle, King County, Pierce County, and the State of Washington, a 50% reduction by 2050 and a 70% reduction by 2040 compared to the 2005 level (NWSA, 2021i). In addition, the GHG emission segmentation (scope system), which WPCI designed, was adopted to emission reduction targets to improve understanding of the port's ability to influence different emitters (NWSA, 2017g). In 2021, the NWPCAS experienced the most dramatic change in the implementation framework, the emission reduction measures integrated with three bottom lines of sustainability, meaning that the social and economic aspects of emission reduction efforts came into prominence (NWSA, 2021c). The emission reduction target was aligned with the IPCCC's global strategy and identified as phasing out all emissions from seaport-related activities by 2050 (NWSA, 2020c).

Chapter 3. LITERATURE REVIEW

We conducted a literature review to identify factors impacting ports' greenhouse gas abatement approaches. Our search of the Google Scholar sources was limited to the following keywords: maritime, seaport, greenhouse gas emissions, decarbonization, green ports, port voluntary environmental management, and port sustainability. This search returned 305 sources. Abstracts of these were read to identify those that were relevant to our research question. This reduced the number of articles included in the literature review to 54. The most widely cited studies were Davarzani (2016) with 187 citations, Winnes et al. (2017) with 165 citations, and Poulsen et al. (2016) with 100 citations.

We categorized the findings from the literature review into four groups depending on how they impact ports' decisions: (Chapter 3.2) technological changes, (Chapter 3.3) economic factors that influence ports' ability to generate revenue and fund GHG abatement, (Chapter 3.4) regulatory requirements and legal constraints, and (Chapter 3.5) political factors, i.e., stakeholders' preferences impacting ports' social license.

In the last decade, there has been an increase in published research addressing port GHG gas emissions and related environmental issues (Bjerkan & Seter, 2019a; Davarzani et al., 2016), including general port, maritime, and ship emissions, eco-efficiency of ports, maritime logistics, energy intensity and economic cost, climate change policy, regulation, carbon tax, carbon footprint case studies, ship mobility emissions, and ship design (Davarzani et al., 2016). Davarzani et al. (2016) reviewed 338 articles related to greening ports and maritime logistics and found out that there is a dramatic growth in the publication of related articles after 2006. Their study also shows that greenhouse gas, emission control, carbon dioxide, air pollution, and carbon emissions are among the top 10 most used words in the title of the articles related to greening ports and maritime logistics (Davarzani et al., 2016).

Some of those papers address the drivers and barriers that affect port authorities' approaches to the implementation of environmental measures, such as carbon management, participation in voluntary emission reduction programs, adoption of corporate sustainability, and adoption of sustainability development. Azarkamand et al. (2020) conducted a survey among 55 port officials, the majority of which were environmental managers who attended the Greenport Congress in Valencia in 2018 to find out port administrations' environmental priorities, to identify primary environmental aspects that port monitor as an environmental performance index, main drivers to implement carbon management program in a port, key stakeholders and major challenges for the development of a carbon management program. The survey results demonstrate that energy consumption, air quality, climate change, and carbon footprint are the top environmental priorities of the participating ports (Azarkamand, Balbaa, et al., 2020). When it comes to main drivers that affect the implementation of carbon management programs in ports, leadership role in carbon management projects is identified as the most important driver, compliance with emerging regulations takes the second place, potential to influence practice and regulation through innovation and investment is the third most influencing driver, opportunity to reduce and offset emissions from infrastructural development and stakeholder pressure to reduce environmental impact take the fourth and fifth place, respectively (Azarkamand, Balbaa, et al., 2020). According to participant port officials' answers, the key stakeholders of the development of a carbon management program in ports, identified in order of importance, are port operators, ship owners, government, senior manager, municipality, port authorities, environmental department, and customers (Azarkamand, Balbaa, et al., 2020). Lastly, the study states that barriers to implementing carbon management programs in ports are data collection, measuring and calculating data, coordination among stakeholders, legislation, external cost, identifying the scope of the emissions, and shipping emissions (Azarkamand, Balbaa, et al., 2020).

Sornn-Friese (2021) tested five hypothetical questions that address the relationship between port size, near port population density, serving the container lines, type of government body of the port (government-owned ports and private ports), type of port (landlord model, service model, integrated model and mixed port model) with the port's tendency to implement voluntary air emission measure in order to explain what factors drive port to adopt air emission measure. The authors identified three primary drivers that led port authorities to adopt emission reduction measures: population density of the near port community, port's business model, and expertise in servicing container shipping (Sornn-Friese, 2021). The study also demonstrates that the port size has a smaller influence compared to the given primary drivers. Landlord ports and ports located near densely populated areas are more likely to adopt pricing measures. Monitoring measures are also widely adopted by ports located near urban areas, while ports near lower population areas tend to adopt bundle measures relevant to pricing and new energy sources (Sornn-Friese, 2021).

Hansen & Steen (2021) conducted a survey among individuals from 96 public and private ports from Norway to explain drivers and barriers to implementing measures for environmental sustainability in Norwegian ports. Hansen & Steen (2021) designated four sets of drivers that affect sustainability efforts in Norwegian ports: steering and governance, relationship with near local communities, economic prosperity, and non-economic sources. The study shows that public ports, specifically those located near urban areas, experience more pressure from their surroundings than private ports to improve their environmental performance since private ports are usually located in more remote areas and specialized to their customers' needs, meaning that they have a better energy and emission management (Hansen & Steen, 2021). Moreover, municipal targets to reduce GHG and other air emission has a greater influence on public ports compared to private ports. Public ports are also more likely to go beyond their commercial interest, such as providing onshore power or alternative renewable fuels to maintain their social licenses to operate (Hansen & Steen, 2021). The authors identified that the economy has a smaller impact on ports' approaches to the implementation of environmental measures, but it is important for providing costly infrastructure such as onshore power (Hansen & Steen, 2021). Non-economic sources are defined as energy resources and knowledge (Hansen & Steen, 2021). Since the source of Norway's 98% of the electricity production is renewable clean energy, port authorities prefer to invest their resources into onshore power projects rather than alternative renewable fuel supply, which is suffering from a lack of demand by port users (Hansen & Steen, 2021).

Godet et al. (2021) carried out a survey among Clean Cargo member shippers, carriers, and freight forwarders to understand what motivates them to disclose their CO2 emissions through a voluntary effort. The authors found that the regulatory environment and technological availability are the main factors to participate in voluntary CO2 emission reporting for Clean Cargo members (Godet et al., 2021). Linder (2018) executed seven interviews with officials port operators, shipping operators, and regulatory agencies and 41 surveys with officials from shipping companies that called at Port of Los Angeles and Port of Long Beach and participated voluntary vessel speed reduction program to explain factors that lead private shipping companies to participate a voluntary environmental program. The study shows that the primary factors that have an influence on shipping operators to participate in vessel speed reduction programs are social and regulatory pressures (Linder, 2018). The authors also claim that stakeholders, particularly ports' internal stakeholders, the near port communities, and regulatory agencies, have a more direct impact on shipping companies' decisions compared to economic motivations (Linder, 2018).

Ashrafi et al. (2020) conducted a systematic literature review to analyze 50 drivers that affect ports adoption to corporate sustainability and the ability to respond to changes in the development and implementation of sustainability strategies. The authors categorize corporate sustainability drivers into four groups according to a multi-stakeholder perspective: governmental perspective, societal perspective, market perspective, and organizational perspective (Ashrafi et al., 2020). They identified regulatory compliance and regulatory license to operate as governmental perspective drivers (Ashrafi et al., 2020). Social legitimacy and social license to operate take place as social perspective drivers (Ashrafi et al., 2020). Market perspective drivers are designated as competitor pressure and customer demand. Lastly, organizational perspective drivers are demonstrated as a competitive advantage, business growth, cooperation, and environmental and social responsibility (Ashrafi et al., 2020).

Giuliano (2013) studied motivation for environmental self-regulation in ports in the case of the Port of Los Angeles (POLA) and the Port of Long Beach (POLB)'s Clean Air Action Plan (CAAP). The author reviewed all publicly available data related to CAAP between 2006 and 2010 and conducted open-ended interviews with key port stakeholders from both ports, including port officials, terminal operators, longshore labor, trucking industry, and environmental advocacy groups (Giuliano, 2013). Moreover, the author conducted a media review on two major newspapers from both cities, Los Angeles Times and Long Beach Telegram, between 2005 and 2010 in order to understand public opinion about the port, international trade industry, and CAAP (Giuliano, 2013). The study demonstrates that the implementation of the CAAP was a part of a strategy to recover the POLB and POLA's social legitimacy, responding to social pressures that were functioning as an obstruction to carry out new projects by ports to expand ports' cargo throughput and to address the regulatory threats (Giuliano, 2013). The result of the research do not provide any evidence supporting the implementation of the CAAP has a positive impact on cargo owners' port selection (Giuliano, 2013). On the contrary, increased costs regarding upgrading the environmental performance of the port can harm the ports' competitiveness (Giuliano, 2013). Moreover, the given investments to implement CAAP did not induce operational cost savings meaning that the regulation was not cost-efficient (Giuliano, 2013). The results also state that along with the launching of the CAAP, ports improved their reputation in the public perception and elevated ports' relationship with the regulating agencies (Giuliano, 2013).

Lozano (2019) conducted 23 face-to-face interviews with internal and external stakeholders of Port of Gälve, Sweden, to understand drivers and barriers in the sustainability adoption effort of the port. The findings of the research demonstrated that the port's internal and external stakeholders' sustainability perspective varies and is dominantly related to environmental and economic issues and their understanding of sustainability practices is mostly related to mitigating port activities' adverse environmental impact on the environment (Lozano et al., 2019). However, the disparity in understanding the sustainability of the internal and external stakeholders can interrupt the investment of the sustainable development of the port (Lozano et al., 2019). The author categorized drivers into three categories according to the previous literature; internal drivers, external drivers, and connecting/corporate sustainability drivers (Lozano et al., 2019). Internal stakeholders' responses show that the most influencing driver is the government (external driver), followed by middle influencing drivers: the business case (internal driver), and society's raising awareness (external driver) (Lozano et al., 2019). The low influencing drivers for sustainable adaptation by the port are identified as international treaties (external driver), regulation and legislation (external driver), reputation (connecting/corporate sustainability driver), stakeholder expectations (connecting/corporate sustainability driver), unions (internal driver), profits and growth (internal driver), employees' shared values (internal driver), shareholder value (internal driver), board of directors (internal driver) (Lozano et al., 2019). Notably, union and board of director drivers are new to the sustainable adoption driver literature (Lozano et al., 2019). Likewise, external stakeholders' understating of sustainability adoption drivers similar to the internal stakeholders; government (external drivers), business case (internal drivers), regulation and legislation (external drivers), and customer satisfaction (external drivers) are designated as middle influencing drivers (Lozano et al., 2019). Low influencing drivers are demonstrated as profits and growth (internal drivers), leadership (internal drivers), employees' shared values (internal drivers), personal engagement (internal drivers), shareholder value (internal drivers), board of directors (internal drivers), international treaties (external drivers), society's raising awareness (external drivers), market expectations (external drivers) and competitors benchmarking (external drivers) (Lozano et al., 2019). In contrast, external drivers did not acknowledge any connecting/corporate sustainability drivers, which could be due to a lack of information about the link between the port and surrounding community, according to the authors (Lozano et al., 2019).

3.1 GHG Emissions abatement measures adopted in ports

A number of scholars studied technologies and tools that mitigate GHG emissions from port activities (Alamoush et al., 2021; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). Authors have suggested different typologies for measures for ports' shift towards sustainability, but generally had a consensus on the definition of sustainable ports—

ports that maintain the balance between Tripple Bottom Line (TBL), meaning that they deliver economic growth while protecting the environment and sustaining social wellbeing (Azarkamand, Wooldridge, et al., 2020; Bjerkan & Seter, 2019a; Hossain, 2020; Lam & Li, 2019). Alamoush et al. (2020) studied technical and operational measures adopted in ports to reduce GHG emissions and improve energy efficiency based on 214 studies and identified 19 measures.

Emission inventories are key tools for reducing GHG emissions from port activities, especially for implementing successful emission reduction measures (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021; Tichavska et al., 2019). Emission data collection allows the port to identify suitable practices to reduce emissions by providing the port's baseline emissions and overall energy consumption (Alamoush et al., 2020; Tichavska & Tovar, 2017). Emission inventories can also be used to track changes in emission and energy consumption trends of the port activities and enable port authorities to evaluate implemented measures' success and the port's overall environmental performance (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Segmentation of the emissions and determination of the emission sources are significant aspects of emission data collection. The WPCI established an emission scope guidance for ports to utilize in their emission inventory applications (Alamoush et al., 2020). The WPCI's emission segmentation consists of three scopes: scope 1 emissions are direct emissions from port's own activities, scope 2 emissions are emissions from purchased electricity, and scope 3 emissions are indirect emissions that port authority has limited influence capacity on sources (Alamoush et al., 2020).

Another key information measure adopted widely in the port industry is monitoring. Monitoring of the GHG emissions enables the port to develop accurate emission inventories and estimate and identify emission reduction targets (Bjerkan & Seter, 2019a). Monitoring implementations also allow port authorities to design and transform their environmental strategies and policies, develop environmental performance index, energy consumption projects, and environmental risk management (Bjerkan & Seter, 2019a). Moreover, monitoring applications deliver social benefits for port administration by allowing them both to estimate and control port activities' external effects (Alamoush et al., 2020). Port authorities can facilitate monitoring to enhance their environmentally responsible image by using monitoring results in communication with the port stakeholders (Bjerkan & Seter, 2019a).

There are mobile and stationary emission sources in the port terminals (Zis, 2015). The mobile emission sources in port terminals are vehicles, on-road heavy-duty vehicles, harbor vessels, and cargo handling equipment (CHE) (Zis, 2015). Studies show that CHE can be responsible for up to 80% of the total container terminal emissions and for consumption of 50-78% fuel energy (Alamoush et al., 2020). The GHG emission measures related to port equipment are limited, costly, difficult to execute, and time-consuming (Alamoush et al., 2020). Old and polluting CHE can be replaced by new or cleaner units, or its engine and fuel can be replaced by cleaner alternatives (Alamoush et al., 2020). Retrofitting the rubber-tired gantry (RTG) cranes' engine can reduce their CO2 emissions by up to 43% (Alamoush et al., 2020).

Winnes et al. (2015) claim that a significant GHG emission reduction from maritime activities can only be achieved by the replacement of traditional fossil fuels with alternative fuels and ports play a key role in the deployment and bunkering of alternative fuels. Ports can also utilize for and even produce from alternative fuels their own operations (Alamoush et al., 2020). The common alternative fuel types adopted in the port industry are liquified natural gas (LNG), methanol, biofuels, and hydrogen battery cells (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis &

Tsoutsos, 2021). Although its GHG emission reduction potential is controversial due to the methane slip problem during the combustion process in the piston engines (Alamoush et al., 2020), LNG applications are getting increasing popularity across the world (Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021) due to the IMO's sulfur regulations and the promotion received from WPCI and EU (Bjerkan & Seter, 2019a). LNG can be utilized in the propulsion of vessels, trucks, CHE, and harbor crafts (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). LNG fuels are 10% more energy-efficient (Alamoush et al., 2020) and generate 25% less CO2 and NOx emissions compared to traditional fossil fuels (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). However, LNG requires expensive infrastructure for distribution, storage, and bunkering applications, which stand as a substantial barrier for implementation (Alamoush et al., 2020; Bjerkan & Seter, 2019; Sifakis & Tsoutsos, 2021).

Likewise, methanol emits less CO2 emission compared to conventional marine fuels and causes no methane slip, but generates GHG emissions during its production (Sifakis & Tsoutsos, 2021), which raises its global warming potential from a life cycle perspective and makes it less advantageous against marine fuel oil(Bjerkan & Seter, 2019a). Hydrogen fuel cells as a marine power have promising potential for greening the maritime industry (Bjerkan & Seter, 2019a). It can be used to propel ships, CHE, and harbor crafts (Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021). Nevertheless, today it is still an immature technology and is suffering from several drawbacks, including cost, challenges in storage and distribution due to its risky nature (Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021). Rarely, biofuels are implemented in the port industry, such as Bio Port in Rotterdam (Alamoush et al., 2020; Bjerkan & Seter, 2019a). Biogas and Liquified biofuels can be produced from ports' own waste biomass and be used in powering trucks which can deliver both environmental and economic benefits (Alamoush et al., 2020; Bjerkan &

Seter, 2019b; Sifakis & Tsoutsos, 2021). Biofuels can also be blended with traditional marine fuels and biodiesel has the potential to reduce GHG emissions by up to 30% compared to conventional fuels (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). However, in common with hydrogen fuel cells, deployment and storage practices of biofuels are costly, complicated, and risky (Sifakis & Tsoutsos, 2021).

Recently alternative power systems, primarily electrification and hybridization, have been utilized to a great extent in the port industry (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Electrification and hybridization of the CHE is the most eco-efficient measure that substantially reduces GHG emissions and the energy cost of CHE operations (Sifakis & Tsoutsos, 2021). Electrification of CHE can lower its CO2 emissions by between 60-80% end energy demand by up to 86.6% (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Moreover, CHE consumes high energy during lifting cargoes. Regeneration braking technology reclaims kinetic energy that is going to be wasted during braking and converts it into a storable and reusable form and sends it back to the local grid. It can provide 60% energy saving in cranes during peak hours (Alamoush et al., 2020). The emission reduction potential of the electric equipment improves when it is combined with smart charging and automatic switch on/off systems (Alamoush et al., 2020). However, the capital cost of both electrification and hybridization of port equipment and vehicles is substantial (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021).

Renewable energy utilization in port operations not only reduces GHG and energy consumption substantially but also improves ports' green image and social acceptance (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Studies show that renewable energy practices reduced CO2 emission from port operation between 2.7% to 80% (Alamoush et al., 2020). Solar energy implementations, both photovoltaic (PV) and solar water heating (SWH), are the most common and mature renewable energy systems in the ports (Alamoush et al., 2020). Solar systems can be established on terminal rooftops, buildings, and warehouses and deliver the best performance when produced electricity is utilized through an onshore power supply (Alamoush et al., 2020). As is the case with solar energy, renewable wind energy has significant potential to reduce GHG emission in ports; however, due to the space limitations of the ports, wind turbines are usually established offshore in its examples in ports (Alamoush et al., 2020). Since the generated electricity by the offshore wind turbines is too large to be integrated with the port grid, wind turbine implementations are usually carried out in cooperation with wind farm companies through energy purchase protocols (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021).

Energy efficiency measures, measures aiming to decrease wasted energy in port operations, are recognized as a key environmental performance indicator and widely implemented by the port at a global level (Alamoush et al., 2020). Replacement of light-emitting diode (LED) lights in warehouses, yards, docs, and buildings combined with auto lighting sensors and PV panels are simple and effective energy-saving measures yielding up to 90% energy saving (Alamoush et al., 2020). Energy management plans (EMPs) are an important key performance indicator for ports as well. EMPs are usually implemented with monitoring tools and aim to reduce energy consumption, GHG emission, and excess loads on the local electric grid (Alamoush et al., 2020). The success rate of the implementation of energy management plans depends on the collaboration of external port stakeholders, the initialization and co-production of knowledge, and the balance between economic and environmental objectives (Bjerkan & Seter, 2019a). Energy storage systems (ESSs) are also effective technologies that can significantly improve port operations' energy efficiency, stability, and reliability if implemented as a bundle with renewable energy and retrieval brake power systems (Alamoush et al.2020; Sifakis & Tsoutsos, 2021). The common ESS types used in ports are batteries, flywheels, and supercapacitors and can be facilitated in both trucks and CHE in terminal operations and have the potential to reclaim %60 of the daily energy usage (Sifakis & Tsoutsos, 2021). Despite their appealing environmental and economic benefits, the reason behind the low implementation rate of the ESSs is the very high infrastructure cost and relatively short lifespan (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021).

Smart grids and microgrids are other energy efficiency measures labeled future of the sustainable ports along with their contribution to the automation and efficiency of port operations (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Smart grid technology is a remote automation system supported by sensors and monitoring tools to optimize power distribution to and from the port grid (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). It can be integrated with ESSs and boosts benefits delivered from renewable energy sources, and its successful implementation with microgrids and other supportive measures, such as virtual power plants that manage energy production hubs to maximize power generation efficiency while greening the power production (Alamoush et al., 2020), could yield a rise in green energy production by 98% and a decrease in carbon footprint by 90% (Sifakis & Tsoutsos, 2021). The last energy efficiency measure studied in the literature is smart load systems (SLM). SLM technology was developed to tackle energy demand fluctuation problems that have been observed more often, along with the increasing implementation of electrification measures of port equipment and onshore power connection (Alamoush et al., 2020). SLM aims to transfer power from off-peak times to peak times, called load shifting, and to ease the stress on the port electric grid at peak times by deploying energy storage systems that were charged during off-peak hours, which is called peak shaving (Alamoush et al., 2020). These automatic applications avoid port terminals exceeding power consumption and facing extra costs on electric bills. If the energy storage systems are charged with clean energy, the SLM system can induce a significant GHG emission reduction (Alamoush et al., 2020).

Digitalization has been improving its popularity in the maritime industry as it does for other industries (Bjerkan & Seter, 2019a). The digitalization measures contain various elements, such as the utilization of cloud computing, the internet of things, big data analysis, and intelligent logistics remote sensing system to improve port's operational efficiency by reducing idling time of shipping and land transportation in terminals and improving communication between internal and external port stakeholders (Alamoush et al., 2020). Automation of the terminal equipment aims to maximize exploitation of the terminal surface and improve energy efficiency while reducing the external effects of the port operations by facilitating automated gate systems, container tracking systems, and optimized truck activities for reducing idling times and congestion in terminals (Alamoush et al., 2020). Overall, terminal automation and operation systems can reduce CO2 emissions by up to 80% in container terminal operations (Alamoush et al., 2020). Other operational measures are executing regular CHE engine maintenance, which has an up to 20% CO2 emission reduction potential by improving the energy efficiency of the CHE operations (Alamoush et al., 2020), strengthening port city integration in waste management, recycling, reuse of heat and steam to provide common benefits to reach both parties climate goals (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021), and implementing green port policies, such as carbon capture projects and providing green commuting to the port employee (Alamoush et al., 2020).

The most common measures to mitigate negative externalities on the environment of land transportation in ports are setting up emission standards for truck engine models to encourage truck operators to upgrade their fleet by truck replacement or retrofitting old polluting engines with cleaner alternatives that meet emission requirements (Bjerkan & Seter, 2019a; Giuliano, 2013;

Gonzalez Aregall et al., 2018). Truck emission regulations are widely adopted in front-runner North American ports, such as POLA, POLB, and Port of Seattle (POS), and delivered notable emission reductions from land transportation activities (Alamoush et al., 2020; Giuliano, 2013; Gonzalez Aregall et al., 2018). However, identification of emission standards for truck engines is made carefully; otherwise, limiting or banning a large number of truck operators from port terminals can negatively affect ports cargo throughput numbers (Bjerkan & Seter, 2019a). Measures addressing truck congestion and idling are common implementations in ports as well. Ports improve technological infrastructure with monitoring and tracking tools to optimize truck movements and arrivals in port terminals which improve overall terminal operational efficiency reduce energy consumption and emissions (Alamoush et al., 2020; Bjerkan & Seter, 2019a). Congestion mitigation fee is also common practice to extend peak hours congestion towards off-peak hours at the terminal gates (Bjerkan & Seter, 2019a). In the port hinterland, transportation, rail systems, and inland shipping constitute a cleaner alternative (Alamoush et al., 2020). Therefore, 35% of the concession contracts contain modal shift/split conditions resulting in additional investment in rail infrastructure and operational optimization tools in terminals (Bjerkan & Seter, 2019a). However, modal split conditions in concession contracts are not popular even though their economic and environmental benefits because of their restricting impact on stakeholder flexibility (Bjerkan & Seter, 2019a). Differentiated port dues for different hinterland transportation methods are utilized to ease congestion in port terminals by extending cargo weight in different ways of the transportation network (Bjerkan & Seter, 2019a).

Onshore power supply (OPS), in other words, cold ironing, is the most studied measure in sustainable port literature and is highly recommended for port authorities to execute due to its compatibility with various application areas and substantial potential in reducing shipping originated emissions in port operations (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Dai et al., 2019; Liu et al., 2019; Orr, 2018; Radwan et al., 2019; Sifakis & Tsoutsos, 2021; Winnes et al., 2015). OPS is the local port grid connection for vessels allowing them to shut off their auxiliary engines and carry out berthing operations with shoreside electricity (Alamoush et al., 2020; Bjerkan & Seter, 2019a; di Vaio & Varriale, 2018; Liu et al., 2019; Orr, 2018; Radwan et al., 2019; Sifakis & Tsoutsos, 2021). The OPS's emission reduction potential relies on the source of the local electricity, performing the best results when it is combined with electricity generated from renewable energy (Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). In Norway, OPS application can reduce GHG emissions by up to 99.5%, while 9.4% in the US and 48-70% at a global level (Alamoush et al., 2020). OPS can also be utilized for electric CHE, charging ESSs, e-vehicles, and harbor crafts (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). According to WCPI's survey held in 2010 with 53 ports, 32% of the ports offer shoreside electricity to shipping lines, and 85% were planning to install OPS infrastructure in their terminals (Bjerkan & Seter, 2019a). Drawbacks of the OPS measure are high capital cost, lack of standardization and complexity in connection tools, limited capacity of the local grid, complexity in implementation due to overlapping responsibilities among port authority and terminal operator, and the lack of consensus in future technology development in the maritime industry (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021).

Another way to reduce shipping emissions in port boundaries is reducing the hotelling time of the vessel at berth (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). Ship turnaround time relies on several factors, including CHE efficiency, berth condition, stevedore operations, and terminal opening hours (Sifakis & Tsoutsos, 2021). Studies show that a 30% reduction in ship turnaround time results in a 37%

reduction in GHG emissions (Alamoush et al., 2020). Reduced turnaround times can be achieved through virtual arrival and just-in-time berthing measures, which aim to reduce hotelling times both at berth and anchor by sharing information among stakeholders (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Moreover, when vessel operators are informed about operation start time in the terminal in advance can provide provision to lower their speed on the voyage to avoid hotelling at anchor and can reduce fuel consumption and GHG emissions (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Reducing vessel speed, in other words, slow steaming, another repeatedly studied and suggested measure by academia (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). Studies state that 20% of speed reduction can provide 40% of CO2 emission reduction; combined with OPS, reduction rates rise up to 71 to 91% (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Port authorities can impose regulations or incentives to encourage vessel operators to reduce their speed within a designated area. Other advantages of the vessel speed reduction measure are the convenience of the implementation and potential reduction in the vessel’s turnaround time at berth (Bjerkan & Seter, 2019a).

3.2 TECHNOLOGICAL FACTORS

There are several technological factors that affect port authorities’ approaches to reducing greenhouse gas emissions whiting port boundaries, including industry dynamics (Moon & Woo, 2014; Zis, 2015), vessel design improvements (Moon & Woo, 2014; Styhre et al., 2017; Zis, 2015), availability of cleaner technologies (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021), logistics and compatibility of alternative marine fuels (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021), source of the port energy (Radwan et al., 2019; Winnes et al., 2015), and port city electric infrastructure (Alamoush et al., 2020; Radwan et al., 2019; Sifakis &

Tsoutsos, 2021). The primary influencing factor is terminal type since container shipping is the most polluting category among other cargo types due to high energy demand for loading/unloading operations at berth (Dai et al., 2019; Zis, 2015). Therefore, the need to address GHG emission from container vessel emission lead port authorities to pick effective, long-term sustainability measures, such as OPS powered by clean energy, which enables container vessels to shut off all auxiliary engines while feeding reefers' energy demand (Sifakis & Tsoutsos, 2021; Zis, 2015). Another fundamental factor impacting port decisions is the average age of the global fleet (22 years)(Winnes et al., 2015). The IMO’s Energy Efficiency Design Index (EEDI) regulation adopts environmental standards for vessels built after 2013 (Styhre et al., 2017; Winnes et al., 2015). Older vessels are less likely to be capable for shoreside electricity connection; therefore, port authorities are required to take capabilities of potential future vessel calls into account while implementing GHG reduction measures (Winnes et al., 2015). The nature of the traditional fossil fuel presents a factor for identifying GHG emission measures for port authorities. Other than GHG emissions, NOx, SOx, and PM emissions are more visible due to their negative health impact on near port communities, delivering more social pressure on port authorities to address public concerns with tools and policies, and GHG emissions are usually reduced as by-catch through NOx, SOx and PM emission reduction measures within port territories (Poulsen et al., 2018). Besides, the capacity of the port hinterland infrastructure is a variable that impacts cargo owners’ decisions (Alamoush et al., 2022). Recently, cargo owners have been seeking ways to reduce the carbon footprint of their entire supply chain and employed multimodal freight transportation and network route optimization applications for their global operations (Poulsen et al., 2016). Therefore, the importance of GHG emissions from port hinterland operations has risen and caused an increase in rail and inland water freight transportation infrastructure improvement investments (Li et al., 2019).

The methodology of data collection in the preparation of emission inventory has a significant role in developing an effective GHG emission reduction strategy in ports since identification, modification, and evaluation of the GHG emission reduction measures are carried out based on emission inventory and monitoring outcomes (Alamoush et al., 2020; Tichavska et al., 2019). Therefore, the demonstration of the scope, emission segmentation, and emission calculation techniques are important factors that have a substantial influence on port authorities' approaches to reducing GHG emissions from port operations (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Tichavska et al., 2019). The availability of new technologies that are compatible with the port operational framework is an influential factor. The employment of a bundle of new technologies in port operations such as digitalization tools, terminal automation systems, virtual arrival, and just in time berthing, real-time information share tools in combination with the smart grid, renewable energy, smart load management, and onshore power supply measures can reduce GHG emission from both mobile and stationary emission sources dramatically (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Tichavska et al., 2019). Likewise, the accessibility of cleaner alternatives of terminal equipment and hinterland transportations units, including electric-powered cargo handling equipment and on-road heavy-duty vehicles, has an essential impact on port authorities' decision-making procedures (Alamoush et al., 2020; Martínez-Moya et al., 2019). Moreover, the improvement of the energy efficiency of the port operations due to the implementation of the new available technologies promotes the port's energy resource reliability, reduces excess stress on the local electric grid, and eliminates delayed response time, confusion, and human error (Alamoush et al., 2020).

Alternative marine fuels have great potential to lead the maritime industry's transition towards sustainability. However, the presence of infrastructure for logistics, emission generation during the production process, and storage risks resulting from their nature are important factors affecting their implementation rate by port authorities (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021; Styhre et al., 2017). The barriers to implementing alternative marine fuels include the methane slip problem of the LNG combustion engines, compatibility of offshore wind generators with the local electric grid, and fluctuation of energy production of solar systems in different seasons (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Sifakis & Tsoutsos, 2021). The OPS suffer from similar technical issues, lack of infrastructural capacity of port terminals, the sufficiency of the local grid, complexity in the compatibility of the electric systems between port and ships are the main technical barriers of OPS applications among ports (Alamoush et al., 2020; Bjerkan & Seter, 2019a; Radwan et al., 2019; Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). Ships are built in different shipyards with diverse standards all around the world and utilize different voltage and frequencies of electricity from 110 to 220 volts at 50 or 60 Hz, meaning multiple connection tools for both parties (Alamoush et al., 2020; Radwan et al., 2019; Zis, 2015). The OPS applications also cause destabilization and overload in the local electric grid in case of the connection of a large passenger vessel or a tanker ship while fuel pumps are running (Styhre et al., 2017). However, OPS has great potential to reduce all types of emissions from various emission sources, especially GHG emissions, since scrubbers and other emission reduction methods for hoteling vessels do not mitigate GHG emissions, up to 99.5% due to the source of the electricity (Alamoush et al., 2022; Styhre et al., 2017; Zis, 2015). The OPS implementation yields the best results when it is combined with renewable energy sources such as hydropower, and the carbon intensity of the local electric grid remains an essential factor to invest in OPS infrastructure for port authorities (Alamoush et al., 2020; Hansen & Steen, 2021; Radwan et al., 2019; Styhre et al., 2017; Winnes et al., 2015).

The vessel design-related factors play an important role in the decision of prioritizing port infrastructure investments, particularly the trend towards larger container vessels (Styhre et al., 2017; Zis, 2015). Increased cargo capacity lowers the cost of and energy consumption for the transported unit (Moon & Woo, 2014; Zis, 2015). In addition, the larger vessel trend leads to smaller vessel fleets resulting in fewer port calls (Moon & Woo, 2014). Therefore, ports are required to provide better service and infrastructure to attract these fewer larger vessels to maintain their competitiveness and secure economic prosperity (Zis, 2015). Correspondingly, ports have been investing in expensive terminal deepening and expansion projects to provide a level playing field for their customers to have them accommodate larger vessels (Zis, 2015). These terminal expansion projects usually include terminal modernization components such as OPS connection, newer and cleaner cargo handling equipment, and other improvements in terminals' technological infrastructure (Zis, 2015). The larger vessels demand more energy for their berthing operations and have a longer turnaround time, resulting in more emissions for each port call (Zis, 2015). The given changes in port business drive port authorities to address increasing negative externalities of port activities with effective measures and policies while maximizing cargo throughput (Moon & Woo, 2014; Zis, 2015). Another design-related factor is vessels' optimum service speed, which affects the effectiveness of the vessel speed reduction measures (Styhre et al., 2017). Exceeding speed reduction in marine engines can cause additional unwanted air pollution generation and increase fuel consumption (Styhre et al., 2017).

3.3 Economic Factors

In the last decades, dramatic changes in the maritime industry, such as the trend towards larger vessels (Moon & Woo, 2014; Zis, 2015), strategic alliances of shipping companies (Ghorbani et al., 2022; Rusinov & Ouami, 2022), and strict environmental regulations at local, regional and international level (Alamoush et al., 2021, 2022; Zanne & Twrdy, 2021), lack of common consensus on the technological and social development in the future of the industry (Bjerkan & Seter, 2019a), and increasing public pressures on the negative externalities (Ashrafi et al., 2019, 2020; Giuliano, 2013; Sornn-Friese, 2021) of port operations, resulted in tougher competition between ports and greater stress on port authorities' investment decisions, particularly to maintain a balance between economic, environmental and social aspects (Moon et al., 2018; Poulsen et al., 2016). The implementation of GHG emission reduction measures is costly, particularly regarding capital costs, has a low return rate and market maturity, and suffers from a lack of infrastructural and logistic capacity (Alamoush et al., 2020; Moon et al., 2018). In terms of alternative fuels, although LNG and methanol are presented as bridge fuels towards zero-emission future marine fuels to a large extent by WPCI and EU, both LNG and methanol require high investment costs for both shipping companies and ports in retrofitting, storage, distribution, and bunkering operations along with low return rate and low demand in the market (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021; Styhre et al., 2017; Winnes et al., 2015). Likewise, electrification and hybridization of terminal CHE and trucks are expensive. However, the combination of the lower maintenance costs compared to fuel counterparts and contribution to the growth of cargo throughput through improving efficiency in port operations makes the electrification and hybridization implementation more appealing in the long term for port authorities (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021).

The economic aspect of the implementation of OPS was widely presented in the literature (Dai et al., 2019; Liu et al., 2019; Radwan et al., 2019; Styhre et al., 2017; Winnes et al., 2015). The primary economic factor influencing OPS implementation is the high initial costs for both vessel retrofitting and terminal installment (Radwan et al., 2019; Winnes et al., 2015). From the port's point of view, annual maintenance and operational costs of the OPS are added to the infrastructure investment (Dai et al., 2019). A study conducted in Danish ports shows that the cost of turning a vessel into shore power capable was calculated as £6.6 million and OPS construction at the terminal was estimated at €37 million (Dai et al., 2019). In addition, WPCI estimated that the annual operational cost of the OPS is 5% of its capital costs (Dai et al., 2019). Dai et al. (2019) studied the economic feasibility of the OPS implementation in a 10-year-period in Port of Shanghai and found out that the only way to make the OPS implementation economically viable for the port is to make a profit out of electricity sale. Another important factor that affects the success of an OPS implementation is the fuel price when shore power connection is not mandatory for vessel calls (Dai et al., 2019; Winnes et al., 2015). The rising price of the low sulfur marine fuels after the IMO's sulfur regulations, along with the ineffectiveness of the vessel-side emission prevention technologies, make the OPS an appealing option for shipping companies (Dai et al., 2019; Radwan et al., 2019). Studies point out that OPS implementations can yield between $70-150 million dollar environmental benefit and worth of $2.94 billion public health benefit if two-thirds of the vessel call facilitated shore power in the US ports (Radwan et al., 2019). The market-based measures allowing carbon trade can increase the return rate of the OPS investments, but economic analysis classifies OPS investments as a highly prohibitive expense along with plug-in-out and queuing delays even though carbon trading enables market conditions (Dai et al., 2019). OPS's high recommendation rate by industry actors and implementation rate by public ports despite its bad financial performance was explained by Hansen & Steen (2021) as the port's effort to go beyond its commercial interest to maintain the port's social license to operate.

Fuel prices are an influencing factor for vessel speed reduction measures in ports as well together with the freight rates (Styhre et al., 2017; Winnes et al., 2015; Zis, 2015). The periodical decreases in the average speed of the global maritime fleet during the 1970s oil crisis and 2008 economic downtown can be used as evidence for the relationship between fuel price and success of slow steaming measures (Styhre et al., 2017; Winnes et al., 2015; Zis, 2015). In prosperous times when low fuel prices and high freight rates are matched, the shipping companies might hesitate to participate in voluntary vessel speed reduction programs since the longer voyage time increases the operational costs and can harm the shipment revenue due to delay in delivery (Tsai et al., 2018; Zheng et al., 2020) even though fuel savings delivered from reduced speed are considerably high (Styhre et al., 2017; Winnes et al., 2015; Zis, 2015). Improvements in terminal technological infrastructure deliver both economic and environmental benefits (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Terminal automation systems, smart grid, smart load management increase port operational efficiency together with port throughput handled (Alamoush et al., 2020; Sifakis & Tsoutsos, 2021). Comparably, peak shaving measures prevent port operations from inducing overload on the local electric grid and preventing ports from additional tariffs on electric bills (Bjerkan & Seter, 2019a). In addition, efficient terminal operations strengthen port competitiveness (Moon & Woo, 2014)., A survey held by Marine Digest & Cargo Business Magazine in 2003, among more than 1200 participant shipping companies ranked the Port of Seattle as the number one port regarding its fast and efficient port operations (Orr, 2018). Furthermore, Orr (2018) conducted a survey among 17 individuals from both the POS and shipping companies asking them to rank the most influential factors that affect shippers' port selection. The survey results show the geographical location, the capacity of intermodal facilities, and efficiency of cargo handling operations carried out at the terminal are the most influential factors for shippers in their port decisions (Orr, 2018). Likewise, Sys et al. (2016) found out that the Port of Antwerp presents a cost-effective solution for cargo owners in terms of hinterland transportation compared to the Port of Mersin and the Port Said, where hinterland transportation operations suffer from congestion. Therefore, the Port of Antwerp is more likely to be selected by shippers working in the Asia-Europe trade market. Consequently, the cost of the hinterland transportation and the time spent in the port terminal are primary factors influencing shipper decisions in the port selection, driving port authorities' approaches to addressing effective GHG measures regarding enhancing port competitiveness (Orr, 2018).

Moon & Woo (2014) analyzed the economic impact of the vessel turnaround time on container shipping companies on a liner service. Their study shows that there is a strong correlation between spending time at port and the annual fuel consumption of the shipping companies. Container vessels' voyage speed in a fixed service schedule is highly affected by changes in spending time at the port terminal since liner service shipping companies aim to maximize the transport capacity of their fleet with the lowest possible costs. Therefore their vessels are assigned to work on a very tight schedule to compensate for recent highly competitive market conditions (Moon & Woo, 2014). According to Moon & Woo (2014), a 30% increase in port time induces an increase in the average voyage speed of the vessel that results in a 30.7% increase in fuel consumption and GHG emissions annually. Likewise, the annual average spending time at the port terminal of a vessel increases by 30%, yields a 17.9% increase in annual port cost and a 20.2% increase in the annual operating cost of a vessel (Moon & Woo, 2014). In addition, the negative impact of longer turnaround time on shipping companies rises when vessel size increases (Moon

& Woo, 2014). Therefore, vessel operators take port terminals' operational efficiency into account when planning their operations to minimize operational expenses, and this situation leads port operators to focus on improving terminal productivity and employ measures such as just-in-time arrival and departure tools, which inform port stakeholders about current berth availability to modify their operations in a most effective manner, to stay in the competition (Moon & Woo, 2014).

The port's competitiveness is a major factor in port authorities' approaches to reducing GHG emissions. Sustainability measures are presented as a driver to take advantage of green marketing opportunities (Lam & Li, 2019; Sornn-Friese, 2021). Sheng et al. (2017) found that implementing a unilateral emission reduction measure by the port has a negative impact on both the shipping company's profit and port's cargo volume and provides an advantage for ports and shipping companies that are not subject to such a regulation. However, Moon et al. (2018) claim that negative outcomes of implementing green policies are experienced in short-term, while ports enjoy positive outcomes of developing sustainable port strategies, including growth in regional economy delivered from ecological industries, such as renewable energy and waste management projects that are established in the port site and strengthen port competitiveness delivered from vitalization of the port cluster in a long-term. The driver of implementing green port strategies is not only attracting cargo owners who value ports' environmental performance but also building a green image in the public and regulator's eye to maintain ports' social license to operate (Lam & Li, 2019). Zanne & Twrdy (2021) went further by claiming economic growth for ports cannot be provided without improvement of environmental performance through implementing green policies simultaneously. Therefore, along with the adoption of sustainable green port policies, port authorities turn negative social and environmental externalities of port activities into an opportunity and strengthen their competitiveness (Zanne & Twrdy, 2021).

The external cost of the air emissions and their calculation methodology were taken place in the literature to a large extent as well (Maragkogianni et al., 2016b; Nunes et al., 2019). There are two main approaches in the calculation of both emissions and external costs; top-down and bottom-up (Nunes et al., 2019; Tichavska & Tovar, 2017). In terms of emission calculation approaches, the top-down method is carried out based on fuel consumption data, while the bottom-up is based on traffic information (Tichavska & Tovar, 2017). For the external cost estimation, the bottom-up approach estimates the cost at benefit from the reduction of emissions, while the top-down approach is employed to calculate external costs based on cost factors taken out of bottom-up approaches (Nunes et al., 2019). The external cost of the shipping CO2, NOx, SOx, and PM emission in Greece ports between 1984 and 2008 was calculated as €3.1 billion based on top-down emission approaches for domestic and bottom-up for international shipping and the top-down method for external cost estimation (Maragkogianni et al., 2016b). In the Port of Kaohsiung, Taiwan, the combination of bottom-up emission and top-down external cost calculation shows that the external cost of CO2 emission in 2010 was $898,000 (Maragkogianni et al., 2016b). Likewise, employment of the same calculation methodologies in Port of Yangschan, China, resulted in $16,485,694 for the external cost of CO2 emissions (Maragkogianni et al., 2016b). At this point, the question arises, “who will pay for the internalization of the external cost of their emissions?” The available sources are to make polluters pay, to use ports’ own revenues, to utilize public funds, or to utilize local, regional, or international development bank funds(Alamoush et al., 2020). The main concern of the public is shifting the internalizing cost of negative environmental and human health externalities of the port operation from the port to the public (Lam & Li, 2019). The given external cost is worth €3.1 billion in Greece port between 1984 and 2008 was reflected in shippers' port operational costs as €2.71 per transported ton (Maragkogianni et al., 2016b).

3.4 Legal Factors

The GHG regulations, at the local, regional and international level, are controversial and affected by many factors, including technical, economic, political, and historical factors(Shi, 2016). The primary challenges arising from the development of GHG regulation are related to GHG emissions nature, particularly their recognition as a pollutant and transboundary nature (Shi, 2016; Tanaka, 2016). Some countries that are party to Annex I to United Nation Convention on Climate Change (UNFCCC) define GHG emissions as pollutants. In the US, the status of GHGs as pollutants remain challenged in courts. Another barrier to regulating GHG emissions is their transboundary and borderless nature, they travel between areas under the jurisdiction of different authorities, so it is challenging to distribute them into specific authorities' accounts (Shi, 2016). The GHG emissions from international shipping particularly suffer from the transboundary nature of the GHG emissions that combine with the transboundary business model of maritime transportation (Shi, 2016; Maragkogianni et al., 2016a; Tanaka, 2016). Accordingly, GHG emissions from maritime-related sources are exempted from Kyoto Protocol, and they are not subject to the Paris Agreements' reduction targets (Shi, 2016; Tanaka, 2016).

The GHG emissions generated from international shipping operations are mainly regulated in the provision of the United Nations Convention on Law of the Sea (UNCLOS or LOSC) and the IMO's MARPOL 73/78's regulatory frameworks. The IMO's Annex IV to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) represents the main global regulatory framework for reducing GHG from international shipping (Godet et al., 2021; Maragkogianni et al., 2016a; Sheng et al., 2017; Sys et al., 2016; Tanaka, 2016; Zis, 2015).

Decarbonization of the international shipping was covered first time by the IMO in MARPOL 73/78 Resolution 8 in 1997 (Maragkogianni et al., 2016a), followed by the adoption of the technical and operational measures; EEDI and the Ship Energy Efficiency Management Plan (SEEMP), both adopted on 15 June 2011 and came into force in January 2013 (Tanaka, 2016). Those regulations also have particular importance as being the first global mandatory GHG rules regulating international shipping emissions (Shi, 2016). The EEDI is a design indicator providing information about the environmental performance of vessels larger than 400 gross tonnage (GT); GT is a function to calculate vessels volume of all enclosed spaces, to ease monitoring and inspection applications by regulatory agencies(Alamoush et al., 2022; T. Lee & Nam, 2017). Furthermore, The EEDI mandates a minimum energy efficiency level per tonne mile for vessels built from January 2013 (Godet et al., 2021; T. Lee & Nam, 2017; Zis, 2015). The IMO's SEEMP regulation aims to reduce GHG emissions from existing ships mandating the implementation of energy efficiency measures that conform with standards set by the IMO for vessel's onboard operations (Alamoush et al., 2022; T. Lee & Nam, 2017; Zis, 2015). In 2018, the IMO adopted its Initial GHG Strategy designating technical (EEDI) and operational (SEEMP) as short-term regulations between 2018-2023, which will be supported with long-term market-based regulations, such as emission trading and global carbon tax regulations (T. Lee & Nam, 2017; Maragkogianni et al., 2016a). In addition to them, as of 2019, the IMO mandated all vessels 5000 GT and larger to share their fuel consumption in the IMO Data Collection System (DCS) (Tanaka, 2016). Lastly, in June 2021, the IMO's Marine Environment Protection Committee adopted MEPC 76 Resolution demonstrating two new regulations called the Energy Efficiency Design Index (EEXI) and Carbon Intensity Indicator (CII) will come into force in January 2026 (Cullinane & Haralambides, 2021). EEXI standards are very similar to EEDI but focus on existing vessels rather than new vessels.

Likewise, CII regulation is identical to SEEMP, but an upgraded version, working as an evaluation scheme addressing the operational efficiency (Alamoush et al., 2022; Cullinane & Haralambides, 2021).

The effectiveness of EEDI and SEEMP regulations have been studied in literature and results show that both EEDI and SEEMP are inadequate due to reaching IMO's GHG reduction targets in a given time period (Tanaka, 2016; Zis, 2015). Therefore, these technical and operational measures were designed to get stricter over time; they still required the support of the market-based measures (Alamoush et al., 2022). Lee et al. (2013) conducted research to explain the impact of the potential regional or global market-based measures on international shipping. Their study shows that the adoption of regional market-based measures, such as including shipping emissions into the EU Emission Trading Scheme (EU ETS), will result in dramatic cargo loss for shipping companies and ports working in European trade routes. In addition, Lee et al. (2013) state that even market-based measures were global and uniform for all subjects, outcomes of the regulation will not be homogenous, in container shipping, routes having longer distances with large vessels will encounter greater operational cost and loss of cargo volume, while small vessels sailing in short distance routes will encounter greater operational cost but an increase in cargo volume. Therefore, the implementation of market-based measures to reduce GHG emissions from international shipping would change competitiveness dynamics for both port and container shipping industries significantly (T. C. Lee et al., 2013).

The effectiveness of the GHG emission regulations in the maritime industry highly relies on the collaboration of multiple jurisdictions, including the flag state, coastal state, and the port state (Shi, 2016). Both LOSC and MARPOL 73/78 frameworks provide primary jurisdiction for the flag state, the state that a vessel registered in its laws regulates GHG emissions from vessels

(Shi, 2016; IAPH, 2020). The flag state is responsible for ensuring the registered vessel's compliance status regarding the IMO regulations, such as the EEDI and the SEEMP regulations. The coastal state, state has rights over the maritime zone where a particular vessel is located. It has limited jurisdiction power over GHG emissions from vessels flying foreign flag even though being the main victim of the generated emissions (Shi, 2016; Tanaka, 2016). The LOCS framework authorizes the coastal state to impose its national laws and regulations on its designated maritime territory, but these regulations cannot be stricter or looser than the IMO regulations to not harm innocent passage right of the vessel flying the foreign flag (Shi, 2016; Tanaka, 2016). In terms of ports and inland waters, the coastal and port state, the state where the port is located while a particular vessel lies, enjoy full legislative and enforcement jurisdiction and is free to impose their national laws or environmental standards as a condition for a vessel's entrance into the port or inland waters (Shi, 2016). The port state's administrative jurisdiction is called port state control and authorized by the MARPOL 73/78 to make an initial or detailed inspection on a foreign vessel (Shi, 2016). Regarding the GHG emissions, the port state control inspections include ensuring whether the vessel has a valid International Energy Efficiency Certificate (IEE), which is given by the IMO to the vessel that is in compliance with EEDI and SEEMP measures (Shi, 2016).

However, although the flag state is given primary jurisdiction over international shipping to regulate GHG emissions, most of the time, the flag state is unable or unwilling to fulfill its responsibility, since environmental penalties are costly (Shi, 2016). Both flag states and shipping companies focus on taking advantage of convenient registering fees and taxes, and this very common concept is called the "flag of convenience (FOC)" (Shi, 2016). Today, 41.8% of the world fleet is by deadweight tonnage (DWT), DWT is a formulation used to calculate vessel's cargo capacity, registered in so-called FOC countries, including Panama, Liberia, and Marshal Island

(Shi, 2016). In addition, the majority of the vessel's GHG emissions occur outside of the territories under flag state jurisdiction, which presents another barrier for flag state jurisdiction's effective enforcement over GHG emissions from international shipping (Shi, 2016; Tanaka, 2016). Likewise, the coastal state jurisdiction's enforcement capacity is limited by its designated maritime zone; it only exercises its power if the vessel is still sailing in its maritime zone, which makes coastal state jurisdiction ineffective in regulating GHG emissions from international shipping (Shi, 2016). Therefore, the importance of the port state jurisdiction becomes prominent in reducing GHG emissions from international shipping along with its enforcement and administration capacity (Tanaka, 2016).

Ports' legal status is an important factor that directly impacts port authorities' ability to reduce GHG emissions (Alamoush et al., 2021; Hansen & Steen, 2021; Zis, 2015). Ports' legal status is classified into three main types; private ports, public ports (service and tool ports), and landlord ports which contain both public and private characteristics (Zis, 2015). Landlord ports present a better performance in terms of sustaining a balance between economic growth, social wellbeing, and environmental protection by considering the port's social responsibilities and negative external effects in decision-making procedures compared to private ports, which aim to maximize profit from available assets (Zanne & Twrdy, 2021). The private companies managing cargo handling facilities under the port regulatory framework are more proactive in responding to market requirements relative to government ownership (Zis, 2015), while publicly selected port governing bodies experience more pressure from public concerns about port operations' adverse externalities and tend to address those given concerns (Hansen & Steen, 2021). The primary drawback of the landlord port is their limited ability to access public funds, which are crucial in implementing GHG measures requiring costly infrastructures (Zis, 2015). Port's governing body is usually named port authorities which owns the land port located and provides rights for private companies through constructal agreements that enable them to manage the port's cargo handling facilities (Zis, 2015). Other responsibilities of the port authorities are providing infrastructure, designing port regulations and environmental standards, maintaining safety for operations and nautical access of the terminals, and coordinating the port's external and internal stakeholders to improve port operations efficiency, in other words, port authorities' main responsibility is to provide a playing field for port users due to the interest of the public goods (Alamoush et al., 2021; Zis, 2015).

As it was mentioned in the introduction section, GHG emissions generated from shipping vessels, hinterland operations, and CHE within the port domain are far more than emissions from the port's own facilities and operations. Therefore, port authorities' ability to influence a substantial part of the port-related GHG emissions is limited (Bjerkan & Seter, 2019a; Martínez-Moya et al., 2019; Zis, 2015) even though they feel more public pressure derived from those emissions and face a danger of losing social license to operate (Sornn-Friese, 2021). Port authorities usually employ port concession agreements with private firms willing to work in port facilities to tackle this issue (Alamoush et al., 2021; Bjerkan & Seter, 2019a; Martínez-Moya et al., 2019). Globally, 85% of the port concession agreements contain environmental clauses, including design and technical standards for vessels and port equipment, bans and limitations, pollution charges, tradable emissions, and requirements for emission data collecting and sharing (Bjerkan & Seter, 2019a). Particularly, concession agreements are widely used by port authorities to reduce emissions from hinterland transportation, particularly to support clean truck programs (CTP) and modal split applications (Bjerkan & Seter, 2019a). Martínez-Moya et al. (2019) claim that the port concession agreements are the most effective instrument that improves port's ability to reduce GHG emission, especially monitoring clauses that lead port operators to monitor their emissions are highly supportive for developing successful sustainability strategies for port authorities. The main disadvantage of environmental clauses in the port concession is that they impose restrictions on port stakeholders' flexibility in their own operations (Bjerkan & Seter, 2019a).

3.5 POLITICAL FACTORS

Political factors are primary drivers that are generated by port stakeholders' interests. There are three conditions that ports should fulfill to be titled green: adopting green policies, practicing scientific monitoring, and the engagement of a broad set of stakeholders (Bjerkan & Ryghaug, 2021; Lam & Li, 2019). The stakeholder term refers to actors that can influence or are influenced by an organization's actions (Ashrafi et al., 2020). The port cluster is formed by several private and public networks, including shipping companies, terminal operators, truckers, rail operators, local communities, regulatory agencies, and indigenous groups (Ashrafi et al., 2020; Castellano et al., 2020). These stakeholders represent complex and different political and economic interests that induce pressure on port authorities. For instance, larger vessel trends in container shipping lead ports to modernize their terminals (Ashrafi et al., 2019; Hansen & Steen, 2021). Therefore, providing communication between diverse stakeholders and their proactive engagement in green strategies is a significant provision for successful implementation (Hall, 2013; Hansen & Steen, 2021). Proactive participation of stakeholders in the decision-making process improves ports' social legitimacy of their actions (Hall, 2013). The stakeholder-related factors can be grouped into four: social, governmental, market-related, and organizational factors (Ashrafi et al., 2020). Examples of stakeholder-related factors are social pressures received from civil society, NGOs, and academia (Ashrafi et al., 2020; Poulsen et al., 2018; Sornn-Friese, 2021), regulatory pressures from government and other regulatory actors (Ashrafi et al., 2020; Giuliano, 2013; Linder, 2018), market pressures from customers and competitors (Ashrafi et al., 2020; Poulsen et al., 2016; Sornn-Friese, 2021) and organizational pressures derived from internal stakeholders (Ashrafi et al., 2019).

Social pressure is a highly influencing factor that motivates port authorities to take an action in environmental upgrading (Ashrafi et al., 2020; Giuliano, 2013; Sornn-Friese, 2021). There are two concepts that need to be explained for understanding social pressure experienced by port authorities: social legitimacy and social license to operate. Social legitimacy indicates the acceptance of a firm or entity’s actions by its stakeholders (Giuliano, 2013; Sornn-Friese, 2021). Ports can maintain their social legitimacy by aligning their operations with regulations, social norms, and values (Giuliano, 2013). Otherwise, loss of social legitimacy negatively affects ports’ social license to operate; the lack of social license to operate may cause restrictions for expansion projects and for the ability to access public resources (Giuliano, 2013; Hossain, 2020; Sornn-Friese, 2021). In addition, lack of social legitimacy might cause protests, lawsuits, boycotts, and increased regulatory pressure that negatively impact ports' economic wellbeing (Giuliano, 2013; Linder, 2018).

Likewise, the threat of potential regulations has a significant potential to drive ports to adopt GHG emission reduction measures (Ashrafi et al., 2020; Giuliano, 2013). Ports can receive benefits of adopting preempt measures that go beyond the regulations, such as preventing stricter regulations or loosening awaiting regulations, improving relationship with regulatory agencies, enhancing the ability to reach resources combined with low regulatory transactions, and guiding future regulations which brings competitive advantage to early adopters (Giuliano, 2013). These preempt implementations that go beyond the regulations, often called “self-regulation,” refer to entities' voluntary actions aiming to provide environmental benefits in consideration of social responsibilities rather than prioritizing economic growth (Giuliano, 2013). By adopting voluntary environmental actions, ports may also can improve efficiency in port operations which strengthens competitiveness and deliver economic benefits as well (Ashrafi et al., 2020; Giuliano, 2013). Moreover, if ports utilize effective communication with the public about the environmental benefits of the voluntary action, they can enhance their social legitimacy and green reputation, which attract customers who account for environmental performance as a key indicator in their decisions (Azarkamand, Wooldridge, et al., 2020; Giuliano, 2013; Linder, 2018).

The CAAP is a good example of a voluntary emission regulation model held in the maritime industry. The San Pedro Bay ports, POLA and POLB, have suffered from public pressure due to being the primary reason for the high-level air pollution in the area (Giuliano, 2013; Zis, 2015). The San Joaquin Valley is still the only area in the US that identified as extreme non-attainment according to the EPA's National Ambient Air Quality Standards (NAAQS) (EPA, 2022). Therefore, public pressures degraded POLA and POLB's social legitimacy and restricted their ability to execute expansion projects (Giuliano, 2013). In 2006, these two competing ports adopted CAAP, a collaborative voluntary action to reduce local air emissions from port-related operations as a response to the loss of social license to operate (Giuliano, 2013; Zis, 2015). Although the CAAP is legally binding for those two ports, it does not involve any formal agreements with legal authorities; they only participated in the development phase of the regulations (Giuliano, 2013). The CAAP has delivered a substantial air quality improvement in the area, strengthened ports' relationship with regulatory agencies, brought the leadership role in the air emission mitigation topic by designating new standards and technologies, particularly for CTPs and gate appointment systems (Giuliano, 2013). However, going beyond the regulations can also induce negative outcomes, including the high cost of environmental measures that might harm ports' competitive advantage while late adopters enjoy adopting proven tools and technologies (Giuliano, 2013). The CAAP was so costly that it could only be adopted by the unified forces of the largest container ports in the US, and instead of attracting customers, it caused business loss for both ports (Giuliano, 2013; Zis, 2015). In terms of GHG emissions, the CAAP presents an effective collaborative, voluntary model for GHG emission actions that is suffered by limited authority and complexity of implementation (Zis, 2015).

The market-related political factors, such as customer pressure, play an important role in environmental upgrading in the maritime supply chain. Cargo type is an essential factor that directly affects cargo owner and shipping company's relationship and on the environmental improvement of the entire global value chain (GVC) (Poulsen et al., 2018; Sornn-Friese, 2021). GVC is the sum of geographically distributed processes of bringing a product into the market from design to recycling (Poulsen et al., 2018). Dry bulk, tanker and container are the primary cargo types in the maritime industry and all three of them have different business models in terms of contract length, distribution patterns, market concentration and bargaining power capacity (Poulsen et al., 2016). In the dry bulk and tanker operations, a vessel usually carries only one owner's one type of cargo, which is usually low value per weight, requiring multiple processes before delivering to the end-customer (Poulsen et al., 2016). The cargo owner and the shipping company contact only once, and operation is carried out from port to port whenever the cargo is ready (Poulsen et al., 2016). Regarding container shipping, the course of transportation processing is held differently. A container ship carries a wide range of cargo that belong to different owners on the same voyage, the cargo value is generally high per weight, and the vessel visits multiple ports en route in a time-sensitive operation (Godet et al., 2021; Poulsen et al., 2016). The container cargo is mostly ready to be delivered consumer goods or semi-manufactured goods, such as electronic devices, retail apparel, and home design products that are produced by brand companies whose success depends heavily on customer loyalty and brand reputation (Poulsen et al., 2016). Therefore, due to the increasing environmental awareness in the global community, brand companies are seeking ways to reduce adverse environmental externalities of their global value chain (GVC), investing in zero carbon, zero waste, and renewable energy projects to minimize operational risks related to their environmental reputation and improve their control over the GVC components (Giuliano, 2013; Poulsen et al., 2016, 2018; Sornn-Friese, 2021).

However, since maritime transportation accounts for only 5% of the total carbon emission in the supply chain and it is known for polluting local air, the brand companies tend to overlook maritime emissions and focus on reducing carbon emissions from their own assets, such as trucking operations (Poulsen et al., 2016). Nevertheless, some large retail companies have begun to evaluate shipping companies' environmental performance they work with, but strategic shipping alliances have enough market power to resist environmental upgrading pressures from their customers (Poulsen et al., 2016). In other words, container shipping experiences more pressure to reduce GHG emissions from their sea and port operations compared to the other type of cargo carriers, but the bipolar governance in the industry delays environmental upgrading in the GVCs (Poulsen et al., 2016; Sornn-Friese, 2021). Therefore, as being a key node of GVC stakeholder's operations, the potential of ports role in enhancing the environmental performance of, particularly reducing GHG emissions from the GVCs, has received increased attention (Poulsen et al., 2018). Although ports are more successful in implementing GHG emission reduction measures in their own operations, as regulators and landlords, they still have the ability to influence GHG emissions generated from ships, terminal operators, trucks, and rail systems working in the port cluster

(Alamoush et al., 2022; Bjerkan & Seter, 2019a; Poulsen et al., 2018). In the scope of port-related GHG emission reduction measures, the visibility of the emissions and the complexity of the implementation of the measure are two primary factors that affect port authorities' decisions (Poulsen et al., 2018). The visibility refers to the level of attention an emission type is received from the public and the level of publicly available data regarding a given emission type (Poulsen et al., 2018). For example, local air emissions, SOx, NOx, and PM are more visible to city residents due to their adverse impact on local communities' health compared to the port-related GHG emissions (Poulsen et al., 2018). The complexity refers to the level of stakeholder involvement in the implementation of the measure (Poulsen et al., 2018). Studies show that port authorities tend to adopt measures that are simple in terms of implementation, or they adopt complex measures if the emission visibility is high (Poulsen et al., 2018). The inclusion of shipping emissions into the EU Monitoring, Reporting and Verification (EU MRV) and IMO's adoption of DCS will increase the visibility of the GHG emissions in the maritime industry (Poulsen et al., 2018).

Organizational factors are usually related to economic pressures, such as strengthening competitiveness by utilizing port resources efficiently through adopting sustainability measures (Ashrafi et al., 2020). Organizational factors also involve governance-related applications, for instance, forming long-term cooperation among port stakeholders to enlarge resources that can be utilized for common benefits (Ashrafi et al., 2019). Port strategic alliances, the collaboration of competing ports called "coopetition," fit into this description. Competing ports can unify their forces to increase their market share, utilize a larger resource for port investments, improve service capacity and competitiveness in the highly competitive industry (Ashrafi et al., 2020). The NWSA is a perfect example of strategic port alliances. Both the Port of Seattle and the Port of Tacoma enjoy mutual economic growth delivered from enhanced competitiveness, managerial experience sharing, enlarged human resources, and resource pooling (Ashrafi et al., 2020). In addition, this coopetiton has increased ports' political power over the regulatory and funding agencies, so the regulatory pressure on the port has decreased, and the secured public funding enabled ports to invest in terminal expansion and sustainability projects (Ashrafi et al., 2020).

Chapter 4. APPROACHES TO REDUCING GHG EMISSIONS BY THE NWSA

This paper employed a descriptive case study design (Yin, 2012) to examine approaches to reducing GHG emissions adopted by the NWSA as well as factors influencing their adoption. We examined publicly available data, including minutes of the NWSA Managing Member's public meetings, supplementary meeting documents, environmental management reports, and financial reports that were published by the NWSA since 2016, the year when the NWSA began publishing reports. We identified technological, economic, legal, and political drivers and capacities impacting the NWSA GHG abatement approaches. Lastly, we outline technological, economic, legal, and political tools adopted by the NWSA.

We identified the following key approaches to reducing GHG emissions: securing external funding (Chapter 4.1), building external policy support (Chapter 4.2), provision of infrastructure, particularly OPS and alternative marine power (Chapter 4.3), and influencing port GHG emission through concession agreements (Chapter 4.4). We address each of these approaches below.

As mentioned in Chapter 2, 90% of the GHG and PM emissions are associated with sea transportation in the Seattle-Tacoma airshed (NWSA, 2021i). Regarding the NWSA and homeport emissions, 87% of the total GHG and 90% of the total PM emissions generated within homeport boundaries are associated with operations under the NWSA administration's control (NWSA, 2021i). In comparison, POS is only responsible for 11% of the total GHG emissions and 7% of the total PM, while POT accounts for 2% GHG and 2% PM emissions. Therefore, the NWSA, as a landlord and regulator, is required to address emissions generated within its boundaries to improve air quality, fulfill its responsibility to tackle global climate change, and strengthen its competitiveness in the Asia-Pacific trade market (NWSA, 2021i). Accordingly, the NWSA declared its gateway-wide air emission plan to achieve targets demonstrated in the 2017 GHG Resolution and NWPCAS, named NWPCAS 2021-2025 implementation plan (NWSA, 2021i).

The implementation plan employs a two-pronged strategy. The first prong includes the identification of ways to reduce emissions from existing fleets, terminal equipment, trucks, locomotives, harbor crafts, and port facilities. The second advocates policies and measures that accelerate zero-emission technology transition (NWSA, 2021i). The port authority takes a threefold adaptive approach— adaptive approach means that the port will track and benchmark the performance of the implementation and will update its strategy every five years; providing infrastructure, such as OPS; strengthening stakeholder engagement and communication; and supporting policies in line with the NWPCAS targets at a local, regional and international level (NWSA, 2021i). The port decision-makers identified five primary conditions for the success of the implementation that are: availability of policy support for zero-emission transition for port operations, presence of external financial support for required infrastructure to adopt zero-emission technologies, adequateness of electricity and alternative marine fuel infrastructure, market maturity of zero-emission technologies demonstrated to port operations, the consensus of the industry actors on the future zero-emission technological and social developments and the qualification of the measure facilitators (NWSA, 2021i).

Before moving forward, it is essential to understand two significant factors that shape the NWSA's approach to implementing GHG reduction measures. First, most of the cargo handled by the NWSA is discretionary cargo, which means that the shipment is not destined for local consumption. It can be delivered through multiple gateway options according to the cost of gateway operations. Accordingly, the adoption of GHG reduction measures that increase the cost of NWSA's port operations can divert the discretionary cargo to competitor ports (NWSA, 2021i). Therefore, the presence of external funds and policy support is vital for the NWSA to maintain its competitiveness while reducing GHG emissions (NWSA, 2021i). Second, the NWSA is a landlord port; it leases its lands to private firms instead of operating itself. Private entities are more agile to respond to changing market requirements. Therefore, the NWSA has a limited influence over port operations within its property. The NWSA can influence private port users' emissions by providing infrastructures, such as OPS and alternative fuel, and imposing environmental clauses through concession agreements (NWSA, 2021i). However, these concession agreements are usually designed as long-term leases to provide a level playing field for port users by minimizing stress on their investments (NWSA, 2021i). Therefore, the NWSA usually needs to receive port users' approval before updating these concession agreements with environmental clauses (NWSA, 2021i).

4.1 SECURING EXTERNAL FUNDING

Today, most GHG emission technologies have not reached their market maturity. Some are still in a demonstration stage and far from being cost-competitive compared to their traditional fuel counterparts (NWSA, 2021i). According to today's prices, the cost of zero-emission measures addressing CHE, truck, and OGV is estimated at $4 billion to the NWSA (NWSA, 2021i). Thus, securing available state and federal air emission grants is vital for the NWSA to reach its GHG emission reduction targets. By now, the NWSA and homeports have adopted measures targeting existing equipment, such as scrapping or retrofitting. However, new ambitious emission reduction targets require the adoption of zero-emission technologies, which necessitates expensive infrastructure and on the more external fund (NWSA, 2021i).

4.1.1 *Federal Grants*

The NWSA has substantial experience in applying and facilitating state and federal funds. But, traditional air emission funds usually do not contain infrastructure grants, so the NWSA's implementation capacity heavily relies on sizeable federal infrastructure funds, such as the Port Infrastructure Development Program (PIDP) and the Rebuilding American Infrastructure with Sustainability and Equity (RAISE) (NWSA, 2021i). In addition, along with the Biden Administration taking over the office, the NWSA's expectations for upcoming federal infrastructure grants aiming at decarbonization have increased (NWSA, 2021i). Other available federal grants are Infrastructure for Rebuilding America (INFRA), Diesel Emission Reduction Act (DERA), Port Security Grant Program (PSGP), Congestion Mitigation and Air Quality (CMAQ) program and Harbor Maintenance Tax (HMT) (NWSA, 2018b).

4.1.2 *State Grants*

In terms of state grants, in the 2021 legislative session, the Washington State Low Carbon Fuel Standard and the Cap and Invest Program were passed and will be implemented in January 2023 (NWSA, 2021i). The NWSA expects that revenues from the low carbon fuel standard program are allocated to port decarbonization projects by the state authorities, along with revenues that the NWSA and its business stakeholders can gain from the emission credit system (NWSA, 2021i). Other available air emissions-related state grants are the Washington State Department of Ecology

(Ecology) Clean Diesel Program, the Washington State Department of Commerce (Commerce) Clean Energy Fund, Volkswagen Mitigation Settlement (VW Grant) and TransAlta Centralia Coal Transition Grant Program Ecology Fund (TransAlta) (NWSA, 2018b, 2021i).

4.1.3 *Factors Influencing the NWSA's External Funding Decisions*

There are several factors that affect the NWSA's approaches to the application and utilization of air emission grants. The availability and the conditions of the funds are important factors. Particularly, the progress of the long-term measures is heavily affected by the fund's availability and evaluation in fund conditions. For example, the Clean Truck Program had been changed due to a new condition of the CMAQ fund called the United States Department of Transportation's (USDOT) "Buy America" standard, which made it difficult to find trucks meeting these requirements. Therefore, the NWSA designed the Clean Truck Fund as a flexible option for truckers to meet the requirements (NWSA, 2018h). Another example of grants' impact is that the DERA grant only covers 25% of the cost of the renewed equipment that is replaced by a polluter counterpart (NWSA, 2018c). The NWSA pursued to use the DERA 2018 grant for replacing leased top handlers and a leased yard truck with two new Tier 4 diesel reach stackers since the electric equipment option is still not economically preferable (NWSA, 2018c). The DERA required scraping old equipment to facilitate funds for buying new equipment, but the NWSA cannot scrap leased equipment, so the NWSA offered to scrap three Tier 0 CHE to meet the required emission reduction level (NWSA, 2018c). The replacement of cleaner equipment is projected to result in a 48% CO2e reduction (231 tons per lifespan) and $264,600 cost savings compared to using old equipment. The two new Tier 4 CHE cost $1.5 million, and $375,000 of it was covered by the DERA fund (NWSA, 2018c). In addition to the coverage limits, the amount of the DERA grant is also restricted by region; Washington State falls into Region 10 along with Alaska, Idaho and

Oregon; and Region 10 was allocated only $1 million DERA fund in the year 2018 (NWSA, 2018c, 2019e).

Maintaining a balance between internal and external funding is another significant factor since GHG emission reduction projects compete with other environmental quality improvement projects, such as stormwater treatment and orca recovery programs (NWSA, 2020b). In the NWSA managing member regular meeting held in September 2020, a commissioner highlighted the balance in internal funding since the shore power projects are expensive and the port's near-term environmental priority is improving water quality (NWSA, 2020c). In addition, maintaining a balance in the distribution of external funds among GHG emission measures is important. The NWSA's VW Grant application for the Terminal-5 shore power project was rejected by the Ecology since the Terminal-5 project was already funded by Commerce's Clean Energy Fund (NWSA, 2019e). If the Terminal-5 shore power project application for the VW grant was approved, the NWSA's other shore power project would less likely be funded, or the grant amount would be low (NWSA, 2019e). Besides the VW Settlement fund for the T-5 shore power project, the NWSA's application for the DERA 2021 fund was rejected because the NWSA had the maximum amount of funding for a shore power project in 2019 (NWSA, 2021f). Likewise, the DERA 2019 grant was allocated to support Husky Terminal shore power because the Terminal-5 shore power project in the North Harbor was already granted funding from other external sources (NWSA, 2020c).

The allocation of the grant amount by polluting sectors and the demonstration of polluter sectors affect the NWSA's grant utilization approach. In some cases, the measures identified to reach the NWSA's GHG emission reduction goals have to compete with similar projects and measures. For example, the VW Grant allocates 45% of its total fund to the marine vessel sectors;

however, the marine vessel sector includes shore power projects, electric ferry deployment, and harbor craft engine replacement (NWSA, 2018c). It is expected that a significant amount of funding will be received by the Washington State Electric Ferry project. Although both diesel ferries and harbor crafts' engines are highly polluting, the potential emission reduction amount from OPS deployment overweights the emission reduction potential of both electric ferries and repowered harbor crafts (NWSA, 2018c). Therefore, the NWSA requested to allocate a whole 45% of the funding of the VW grant for shore power projects by emphasizing the effectiveness of the shore power infrastructures. For example, OPS allows the port to increase refrigerated cargo capacity without backup diesel generators and additional cargo handling equipment and charging stations (NWSA, 2018d).

The ownership of the infrastructure or the equipment is also a significant factor. For example, VW Grant covers 100% of government-owned OPS deployment projects while it covers up to 75% of the replacement cost of the non-governmental CHE (NWSA, 2018c). Therefore, in some cases, the NWSA plays a bridge role for its business partners to reach public funds, such as the NWSA allocated $132,000 of secured $782,482 DERA grant for its terminal operator, Rail Management Services (RMS), to support its purchase of six electric yard tractors (NWSA, 2021g). Likewise, the NWSA plans to utilize VW Grant to subsidize electric utility entities' infrastructure improvement projects for OPS installation (NWSA, 2018c). Transfering some part of the secured funding from one specific project to another is possible but requires a legal grounding (NWSA, 2019e). The NWSA decided to utilize the $1.2 million funds remaining from the CTP for OPS installment projects (NWSA, 2020b). The Washington State Department of Ecology initially provided the grant to reimburse truck owners who participated in the CTP (NWSA, 2020b).

However, the language of the bill was required to change (NWSA, 2019e), and the Ecology's permit was also required to reallocate this $1.2 million worth of funds (NWSA, 2019e)

The NWSA's relationship with the regulatory and funding agencies at the local and national levels plays a crucial role in securing air emission funds since multiple agencies review most of the grants' application process. For example, although CMAQ is a federal grant, the grant approval is given by Puget Sound Regional Council (PSRC) (NWSA, 2019c). The CMAQ also requires the approval of the Washington State Department of Transportation (WSDOT) and the Seattle Department of Transportation (SDOT) (NWSA, 2019c). Similarly, the federal VW Grant's distribution is under the Ecology administration's control (NWSA, 2018c). The relationship between environmental agencies of the regions that create opportunities for the NWSA to participate in environmental projects is also a significant factor. For instance, the trucking companies regularly calling the NWSA had a chance to replace their old trucks with 2012-2014 model trucks far below their market value since they were no longer compliant with environmental standards in California ports under a partnership between the California South Coast Air Quality Management District (SCAQMD), the Puget Sound Clean Air Agency (PSCAA), and Oregon Department of Environmental Quality and the NWSA (NWSA, 2018l)

Other important factors in securing external funds are grant application and project completion deadline. The NWSA could not benefit from VW Grant for CTP because the funding was received after the CTP application deadline, and the VW Grant is only available for the new truck, which is not appealing for truck owners even with 50% grant support (NWSA, 2018c). From the project completion deadline aspect, due to the uncertainties in the CTP's deadline dates, the PSCAA decided to allocate the DERA 2018 fund to another emission reduction project (NWSA, 2018e). Completion time of the project is also important, especially for OPS installment projects.

The average completion time of the OPS installment projects is 2.5 years, and the NWSA set a target for OPS projects to be funded 50% externally. If the 50% target is achieved, the annual cost of an OPS project will be between $1 and 2 million to the NWSA budget (NWSA, 2020b). Thus, to improve the practicability of the OPS projects, the NWSA accelerated its external funding applications (NWSA, 2020b). Lastly, the competitiveness of the NWSA projects applying for air emission grants was noted as an essential factor in securing external funds (NWSA, 2021f).

4.2 Building External Policy Support

The NWSA's influence capacity over port-related GHG emissions is restricted by legal and economic factors, mainly from its business model and market conditions. In the NWSA case, the success of the GHG emission reduction implementations heavily relies on the availability of external funds and policy support at a local, state, federal, and international level (NWSA, 2021i). Therefore, the NWSA advocates for regulations and policies that reduce competitive pressure on the NWSA's GHG emission reduction efforts and accelerate the transition towards zero-emission technologies (NWSA, 2021i). The NWSA also actively seeks ways to strengthen its relationship with regulatory and funding agencies, including the IMO and WPCI at the international level; EPA, the US Department of Energy and the US Department of Commerce at the federal level; the Ecology, the Commerce, WSDOT and PSRC at the state level; and PSCAA and public utility firms, Seattle City Light and Tacoma Power at the local level (NWSA, 2021i).

The NWSA utilizes several communication tools to inform its stakeholders about the implementation milestones and possible future efforts. The common communication tools adopted by the NWSA are testimony and private meetings, and publishing legislative agendas to establish signals informing the NWSA expectations to the government agencies (NWSA, 2017d, 2021i). Each year, the NWSA prepares three legislative agendas: federal, state, and local legislative agendas, to address issues influencing the NWSA's business plan (NWSA, 2017d). In addition to the legislative agendas, the NWSA publishes a catalog of governmental relations positions report annually (NWSA, 2017d). The NWSA's catalog of governmental relations positions report is designed as a proactive instrument that represents the port's expectations and its possible support or opposition associated with future regulation (NWSA, 2017d). For example, in the catalog of governmental relations positions reports published between 2017 and 2020, the NWSA showed its advocacy for possible future clean fuel standards, carbon tax, and overall climate change policies that are not passed yet in the WA legislation (NWSA, 2017d).

In terms of legislative agendas, the NWSA usually addresses continuing issues influencing the NWSA operations (NWSA, 2017d). These addressed issues should be actionable, measurable, and comprehensive for external stakeholders (NWSA, 2017d). The GHG emissions-related topics were usually mentioned in the state legislative agendas since the majority of the state and federal external fund programs are managed by state agencies (NWSA, 2017e, 2017f, 2018m, 2019h, 2019i). The topics that have been addressed in the state agendas are the Terminal-5 shore power project, CTP, VW Grant, SEPA and GHG emissions, the Clean Energy Fund, and the Clean Fuel Standards (NWSA, 2017e, 2017f, 2018ma, 2019h, 2019i). In comparison, the NWSA addressed sizeable infrastructural topics such as electrification and renewable energy in the federal agenda since the port expects large port decarbonization funds from the federal infrastructure packages (NWSA, 2021h).

4.3 PROVISION OF INFRASTRUCTURE

The OPS is the most addressed GHG emission reduction measure in the NWSA's publicly available documents. The NWSA is planning to build shore power infrastructure at all terminals by 2030 in the scope of NWPCAS and the port's 2017 GHG Resolution (NWSA, 2018c). By investing in the OPS installment projects, the NWSA aims to take advantage of state and federal level external funding opportunities, reduce port-related local air pollution and GHG emissions that have an adverse impact on citizens of King and Pierce Counties and the global climate change (NWSA, 2018c, 2020b).

4.3.1 *Drivers for On-shore Power Supply Implementation*

According to the 2016 PSEI, GHG emissions from vessels at berth position account for 10% of total GHG emissions of the NWSA operations (NWSA, 2018n)**.** The most cost-effective way to reduce GHG emissions from hotelling vessels at berth is to provide shoreside electricity connection, especially if the carbon intensity of the local electricity is low (NWSA, 2019a). There are emission reduction technology alternatives for the OPS, including the barge-based “hood” system that eliminates air emissions by connecting the exhaust outlet of the vessel to block exhaust gas from going off (NWSA, 2018n). Another method is barge-based and container-based generators, simply placing a container equipped with LNG generators on a vessel deck to supply energy for hotelling operations (NWSA, 2018n). However, emission capture and treatment systems are costly and cannot mitigate GHG emissions; remaining OPS is the most cost-effective method of cutting emissions from the vessels at berth. (NWSA, 2020b).

As mentioned above, OPS GHG emission reduction potential heavily relies on the source of electricity production (Winnes et al., 2015). The source of both Seattle City Light and Tacoma Power’s electricity is hydropower, meaning nearly zero-emission during the electricity generation process (NWSA, 2020b). In addition, the Washington State Clean Energy Transformation Act mandates to make carbon-neutral the source of states electricity by 2045 (NWSA, 2021g). Therefore, utilizing OPS at the NWSA terminals eliminates almost all air emissions from vessels, reefers and electric equipment.

OPS projects are also in line with terminal modernization projects that are carried out to address the changes in the industry, such as larger vessel trends. There have been multiple terminal modernization projects taking place within the NWSA, including Terminal-5 Modernization and T-3 and T-4 Pier Modernization projects. The Terminal-5 Modernization project is estimated between $365 and $380 million. It will be able to host two ultra-large vessels simultaneously with the wharf equipped with 12 cranes capable of servicing EEE (18,000TEUs or larger vessels) along with shore-to-ship power infrastructure (NWSA, 2019d). The Terminal-5 OPS infrastructure cost was $11.8 million, and 4.4 of them were reimbursed by the Commerce's Clean Energy Fund. In 2018, both T-3 and T-4 terminals' wharves were reconstructed, and electrical infrastructure was obtained by allocating more space for shore power construction (NWSA, 2021b). In the first place, the cost of the shore power connection was calculated at $5,651,000, but this amount doubled to $11.6 million after reassessment of the port staff expanding the project to accommodate 14,000 TEUs and larger vessels and to provide sufficient power for shore power with electrical infrastructure (NWSA, 21f).

Another driver that motivates the NWSA to adopt the OPS measure is an increase in the number of shore power connection capable vessels working in the Asia-pacific trade (NWSA, 2018c, 2020b). The portion of shore power capable vessel calling at the NWSA's six major international terminals increased from 40% to 55% between 2018 and 2020 (NWSA, 2018c 2020b, 2021f). The increase in shore power capable vessel calling at Asia-pacific ports delivered from several reasons, including the State of California enacted shore power standards that require shipping lines to meet 80% of shore power capable vessel calls in California, combined with Port of Vancouver's two shore power ready terminals completion with shore power incentive programs and aggressive shore power development in Chinese ports (NWSA, 2018c, 2020b). Therefore, the

NWSA is expecting that the number of shore power capable vessels will continue to increase steeply in the Pacific Rim trade and planning to build shore power connections at its all terminals by 2030 (NWSA, 2021f).

In addition to OPS's emission reduction benefits, the shore power can deliver economic benefits by attracting beneficial cargo owners (BCOs), such as Maersk, an industry giant, offering carbon-neutral transportation options for its customers (NWSA, 2020b). Another commercial benefit of the shore power is strengthening the NWSA's green gateway image, especially in competition with other west coast ports that enacted their own shore power regulations (NWSA, 2020b). Also, shore power can deliver cost-saving for both vessel operators and the port since electrical systems' operational and maintenance costs are lower than diesel counterparts (NWSA, 2019e, 2020b). Besides these benefits mentioned above, if the Washington State implements low carbon fuel standards that are similar to the California example, and if they allows participants to generate carbon credits with shore power that can be traded with high-polluting participants, the NWSA, terminal operators, and shipping companies would take advantage of going beyond the regulations by generating revenue from selling carbon credits (NWSA, 2020b, 2021i).

Other drivers mentioned in the NWSA publicly available documents are the trend towards larger vessels, the average age of the global fleet, frequently changing container shipping strings. The larger vessels spend more time at berth, and their auxiliary engines consume more fuel in berth operations (Moon & Woo, 2014). Therefore, OPS's GHG emission reduction capacity will be increased along with increasing vessel size (Moon & Woo, 2014). The global fleet's average age is 22 (Winnes et al., 2015), and the NWSA is expecting an acceleration in fleet modernization investments from shipping companies. New built ships are more like to be built as shore power connection capable (NWSA, 2018n).

The container vessels are usually assigned in a fixed schedule string routing operations, meaning that the vessel calls multiple ports on its route (Godet et al., 2021; Poulsen et al., 2016). However, due to the highly competitive nature of container shipping, these shipping strings are frequently taken over between competitor shipping lines, meaning that the same cargo owners' good is transported by a different vessel on the same string (NWSA, 2018n). Therefore, different vessels encounter and are required to comply with the same environmental regulations imposed by port and coastal jurisdiction located on the route (NWSA, 2018n). For instance, the number of annual vessel calls in California ports is 25 times greater than the Northwest ports; and the NWSA usually takes place in these strings, containing California, Vancouver, Chinese ports (NWSA, 2020b). Consequently, the effectiveness of the OPS measures adopted by the NWSA is enhanced by increasing shore power connection installations on vessels that are willing to work with ports that are on the same string as the NWSA and require OPS connection at berth (NWSA, 2020b).

Besides given drivers above, the NWSA expects that a gateway wide OPS strategy, in combination with homeports' zero-emission strategies: the South Harbor Electrification Roadmap and the Seattle Waterfront Clean Energy Strategic Plan, will present an effective communication instrument that strengthens the port's relationships with regulatory and funding agencies by expressing port's determination for reducing port-related air emissions and increase the NWSA's chance to secure public funding (NWSA, 2020b, 2021f). Lastly, the NWSA has experience installing OPS at its terminal in combination with utilizing public funds (NWSA, 2020b). The TOTE Terminal in South Harbor was equipped with shore power, and the project cost was covered by an EPA grant (NWSA, 2020b). Therefore, the NWSA's experience in OPS implementation is expected to improve the competitiveness of its applications for air quality grants.

4.3.2 *Barriers for On-shore Power Supply Implementation*

The primary barriers for the NWSA's OPS implementation are the sizeable cost of OPS infrastructure combined with low return rate, inadequate external funds, uncertainties in the future of zero-emission technologies demonstrated for port operations, and lack of OPS regulations at a local and global level. Although OPS measures are considered the most effective way of reducing vessel emissions at berth position, their emission reduction potential is limited compared to total GHG emissions occurring within the NWSA boundaries (NWSA, 2021i). The total cost of building gateway-wide shore power infrastructure makes up $68.68 million additional $3.2 million for the reefer plugging system, and $8.2 million for electric distribution systems. (NWSA, 2018c). If the NWSA's major international terminals were equipped with shore power, the amount of eliminated GHG emissions were going to be 14,130 tons, and if all vessels were shore power capable, the GHG emission offset was going to account for 24,675 tons (NWSA, 2021f). More specifically, OPS's emission reduction capacity at Terminal-5 and Husky Terminal was calculated as 2.5 and 5.5% of total GHG emissions from the NWSA, respectively (NWSA, 2021i). At the same time, their installment cost was considerably high, $11.8 and $12.3, respectively (NWSA, 2018c, 2021i).

Another economic constraint for OPS implementation is the lack of public funds. Since OPS connection is not mandated in Washington State and OPS infrastructure projects are costly, operational cost-savings are far smaller than its capital cost. Therefore, supporting OPS projects with external funding is vital for achieving gateway-wide OPS implementation target (NWSA, 2020b). As mentioned in Chapter 4.1.3, the NWSA set a 50% external fund target for the OPS implementations to mitigate their burden on the NWSA's annual budget since the OPS measures are in competition with other environmental projects for NWSA's internal fund (NWSA, 2020b).

According to the NWPCAS 2021-2025 implementation plan, the external fund gap for OPS projects was estimated at nearly $20 million to achieve the given 50% target (NWSA, 2021i), even though a substantial amount of the secured fund allocated to OPS projects (NWSA, 2021e). So far, the NWSA has allocated a $1 million DERA 2019 grant, and $1 million from TransAlta for Husky Terminal OPS infrastructure project, $2 million from Ecology's VW Grant for the T-18 OPS project, $4.4 million from Washington State's Clean Energy Fund for T-5 OPS project (NWSA, 2021e).

The NWSA also applied for the VW grant for the Terminal-5 shore power project, but the state rejected it because the state already provided $4.4 million reimbursements from the Clean Energy Fund, which is administrated by the Washington State Department of Commerce, for the OPS project at Terminal-5 (NWSA, 2021e). However, if the Terminal-5 shore power project application for the VW Grant were approved, the NWSA's other shore power project would be less like to be granted, or the grant amount will be reduced (NWSA, 2019e). Likewise, the NWSA's DERA 2021 application for the Terminal-5 OPS project was rejected by the Ecology due to the same reason: the project was already funded by the state (NWSA, 2021f). Another restricting condition in the air emission grant that the NWSA secured was the VW Grant is limited to $2 million per OPS project, so the T-18 OPS project, which was projected to cost $27.7 million and only received $2 million from the VW Grant (NWSA, 2021d).

To achieve the NWPCAS's phasing-out all emissions by 2050 target, the required emission reduction from the OGV sector is not realistic since no technology can deliver substantial emission reduction in OGV operations unless transition to zero-emission fuels (NWSA, 2018n). In addition, the IMO's identified GHG emission reduction targets for international shipping do not align with the NWPCAS targets (NWSA, 2018n). Therefore, ports' voluntary efforts to reduce port-related emissions, particularly the OPS measure, have increased its popularity. However still, port authorities suffer from uncertainties delivering from inadequate electric infrastructure, lack of global standardization for OPS connection plugs, and lack of local and global regulations supporting OPS utilization (NWSA, 2018c). To overcome the lack of global standardization, the NWSA adopt California plug-in standards at its terminals since most of the shipping lines install OPS connections on their vessel to comply with California ports' OPS requirements (NWSA, 2020b).

Since the NWSA is a landlord port, once the OPS is installed at its terminals, terminal operators will be responsible for utilizing OPS operations, which means that additional labor and administration expenses and commissioning with vessel operators, ending up extra cost and complexity on their regular business and would result in a competitive disadvantage (NWSA, 2020b). Therefore, the NWSA planned to keep OPS implementation on a voluntary basis until all terminals are equipped with the shore electricity connection or the state lawmakers implement shore power connection at the NWSA terminals mandatory (NWSA, 2020b). However, OPS installation at Terminal-5 was a condition of both the Master Use Permit (MUP), which is given by the Seattle Department of Construction and Inspection (SDCI) and Memorandum of Understanding (MOU), which is not legally binding, but present that parties will work together in the same direction, with was held between the NWSA and PSCAA (NWSA, 2021e). In addition, both MUP and MOU require the port to implement an air quality management program collaborating with terminal operators to maximize shore power use (NWSA, 2021e). The Final Environmental Impact Statement (FEIS) for Terminal-5 Modernization Project requires shore power usage commitments or delivering the same PM 2.5 emission offset (NWSA, 2019d). In other words, FEIS requires the port to ensure that the shore power usage is 30% percent once the terminal starts servicing, 50% after ten years, and reach 70% percent by the end of the 19th year. Also, in the FEIS, the portion of Tier 4 cargo handling equipment is required to be 75% in the beginning, 95% in the 11th year, and 100% by the 20th year, or the PM2.5 emissions originating from the port operation at T-5 will be less than 6 tons per year in the first 10 years, 5.9 tons per year between 11th and 19th years, and 4 tons per year after 20th year meaning that shore power will be not necessary if the cargo handling equipment complies with the Tier 4i or better requirement and cargo volume stay below 647,000 TEUs (NWSA, 2019d).

4.3.3 *Evaluation of On-shore Power Supply Investments*

As mentioned in Chapter 4.2, the NWSA plans to install OPS at all terminals. However, the port's initial OPS implementation target is to install OPS at its major international terminals: Terminal-5, T-18, and T-30 in the North Harbor; Husky Terminal, Washington United Terminal (WUT), and Pierce County Terminal (PCT) in the South Harbor since OPS capable vessels calling at these terminals make up a larger portion than the other international terminals (NWSA, 2019e). Therefore, one factor influencing the NWSA's approach in prioritizing the OPS project is the number of OPS capable vessels calling at a particular terminal (NWSA, 2020b). For example, in 2020, Husky Terminal and WUT host the same amount of vessel calls, 86 and 83, respectively. Even so, 78% of the vessels called at Husky were OPS capable, while this portion for WUT was 47% (NWSA, 2021i). Moreover, OPS capable vessel calls at Husky Terminal spent more time at berth in average, meaning that OPS deployment in Husky Terminal has an immense potential to reduce GHG emissions compared to deployment in WUT (NWSA, 2021i).

Another important factor is the project's cost, including electric distribution infrastructure (NWSA, 2020b). The projected cost of the OPS infrastructure varies from terminal to terminal, such as the cost of Husky Terminal is $11.1 million, T-18 is $27.7 million, WUT and PCT together is between $24.5 and $55.4 million (NWSA, 2021i). Remarkable, according to the 2018 air quality funding document, the costs of OPS installation at these terminals are far lower, meaning that the cost of the OPS projects changes over time along with the rapid changes in the industry (NWSA, 2018c). Compared to not plug-in scenarios, operational cost and possible cost-saving of OPS utilization are important indicators for the NWSA (NWSA, 2018n). The operational cost of OPS implementation depends on electric and fuel prices, maintenance costs, and additional labor costs (NWS, 2018n). Lastly, the competitiveness of the OPS project for external funding is an essential factor for prioritizing an OPS project (NWSA, 2019e). However, the NWSA places emphasis on distributing its resources equally to homeports, which is also a key factor for external funding applications for OPS projects (NWSA, 2019e)

4.3.4 *Conditions for Successful On-shore Power Supply Implementation*

Since connecting to OPS is not mandatory in Washington State ports, providing land electricity does not mean that it will be preferred by all capable vessels calling the NWSA terminals (NWSA, 2018c). In order to make shore power connection an appealing option for terminal operators and shipping companies, the NWSA should promote possible cost-saving that would be delivered by connecting port electric instead of consuming ultra-low sulfur fuel (ULSF) (NWSA, 2018c). The cost-saving potential of plugging in OPS connection relies on multiple factors, including fuel price, source of the electricity, utility rates, labor expenses, and carbon pricing policy (NWSA, 2020b). In combination with the IMO’s ECA regulation and decreasing popularity of exhaust scrubbers due to their unexpectedly high maintenance cost and polluting behaviors, fuel prices are projected to increase in the near future (NWSA, 2020b). Moreover, electricity price does not fluctuate as fuel price does, so it can be considered a more reliable source of energy (NWSA, 2020b). In a situation where fuel prices are down more than expected, the NWSA is planning to adopt an incentive program to maximize shore power use (NWSA, 2021f).

The difference between connecting to OPS and burning ULSF can be calculated with the given fuel price in 2019. The cost of OPS connection is $9,870, while the cost of burning fuel is $12,344 at Husky Terminal in South Harbor, with the given average hotelling time at berth 72.9 per call (NWSA, 2020b). The situation for North Harbor is different due to the business model of the Seattle City Light, in which the existing rate contains a demand charge, so the monthly bill is shared by vessels (NWSA, 2020b). On that account, the more shore power capable vessel results in a less operational cost for shipping operators in the POS terminals (NWSA, 2020b). On average, the cost of using fuel at berth is $16,483 per visit at the NWSA's major terminals, while the cost of shore power is $15,199, %8 percent lower (NWSA, 2018n). The cost-saving from plugging in can reach up to 19% if labor expenses are taken out (NWSA, 2018n). Labor expenses depend on the contract between the terminal operators and workers (NWSA, 2018n). In the NWSA case, labor and administrative costs together were calculated at $600 per vessel (NWSA, 2020b)

The primary motivation to plug-in shore power for vessel operators is operational cost (NWSA, 2020b). At this point, developing a special rate in collaboration with utility companies is essential in order to incentivize port electricity (NWSA, 2020b). In the case that Seattle City Light and Tacoma Power provide better rates for OPS electricity in combination with low electricity prices in Washington state, 10-20% of cost-saving is possible with plugging land electricity for shipping companies compared to consuming ULSF (NWSA, 2018c). However, the non-ignorable gap between rates presented by the two companies induces the billing process to be tangled and less preferable for shipping companies (Tacoma Power rate: $8.35 per kW vs. Seattle City Light rate: $3.39 per kW) (NWSA, 2020b). Tacoma Power volunteered to develop a special rate for the shore power grid in South Harbor (NWSA, 2020b). However, Tacoma Power identified three obstacles to developing a special rate for South Harbor's OPS implementation (NWSA, 2020b). First, peak demand charges induce a complicated redistribution process for terminal operators, making shipping operators hesitant to connect shore power (NWSA, 2020b). Second, demand ratchet charges would bring an additional burden on terminal operators' plates even though the power was not used, resulting in harming terminal operators' competitiveness (NWSA, 2020b). Lastly, Washington State laws and Tacoma Municipal Code do not allow customers to resell electricity except the rate language address to authorize reselling (NWSA, 2020b). Utility companies need an incentive to provide better rates; therefore, the VW Grant presents an essential opportunity to cover utilities' infrastructure improvement costs (NWSA, 2018c).

4.4 Concession Agreements

The NWSA, as a landlord port, has limited ability to influence port tenants' day-to-day operations (NWSA, 2021i). One effective way to influence port users' GHG emissions is by imposing environmental rules through concession agreements (NWSA, 2021i). The NWSA uses concession agreements in OPS and CTP implementations by updating long-term concession agreements with terminal operators (NWSA, 2021i). The NWSA aims to add clauses related to laboring and billing procedure in terminal operator concession agreements to make OPS utilization convenient for all parties by the time projects are completed (NWSA, 2018e, 2021i). In the CTP, the NWSA imposed engine emission standards for trucking companies through the same method by updating long-term concession agreements with terminal operators since the port has insufficient political power to ban non-compliance trucks (NWSA, 2017c, 2021i).

4.4.1 *Clean Truck Program Background*

In 2008, along with the launching of the NWPCAS, the participating ports adopted the CTP by identifying standards for truck engines (NWSA, 2017c). The NWPCAS truck engine standards have evolved over time; the initial target was to remove pre-1994 model engine trucks by 2010 (NWSA, 2017c). After that, the target was updated as meeting 80% compliance for trucks calling at participating ports' terminal should be 2007 or newer models by 2015; and 2007 engine standards targets were updated to reach 100% compliance by 2018 (NWSA, 2017c). The 2007 model engines standards identified under the EPA's guidance, according to the EPA, 2007 model engines are ten times cleaner in terms of local air pollutants than previous models (NWSA, 2017c). The NWSA was involved in CTP in 2015, simultaneously with its involvement in the NWPCAS (NWSA, 2018e).

The NWSA's major international terminals that participated in CTP are Husky, Pierce County Terminal, Washington United Terminals, and East Sitcum in the South Harbor; T-18, T-30, and T-46 in the North Harbor (NWSA, 2018e). The port officials sought ways to expand the scope of the CTP implementation by including domestic terminals. The number of trucks working through the domestic terminal is one-eight of the number of trucks calling on international terminals, and those which trucks mostly overlapped (NWSA, 2019g). Therefore, the staff decided not to implement the clean truck program on the domestic terminals, rather decided to track the number of non-compliant trucks calling on domestic terminals (NWSA, 2019g). In addition, technological infrastructure installment cost was calculated as $776,000, which was another factor that influenced the port's decision (NWSA, 2019g).

The CTP is a common measure adopted by ports worldwide to reduce port hinterland emissions. There is also alternative implementation for CTP, such as grandfathering the non-compliant trucks, implemented by the Port of New York and Port of New Jersey (NWSA, 2018e). The two ports committed to investing $50 million in reducing air emission technologies in other sectors, including OGVs and CHEs, instead of implementing 2007 or newer engines for truckers (NWSA, 2018e). However, in the NWSA case, if this alternative was adopted, it could have induced inequality for truckers, particularly those who invested in fleet modernization (NWSA, 2018e).

4.4.2 *Motivation for Implementing Clean Truck Program*

The NWSA's primary motivations for implementing CTP are reducing air emissions in its hinterland operations and improving port operational efficiency by enhancing terminal gate technological infrastructure (NWSA, 2018e). Since trucks calling at the NWSA terminal spend most of their time outside the port boundaries, by implementing CTP, the NWSA also reduces air emissions occurring within near port areas and collaborates with port cities' urban sustainability (NWSA, 2021e). In addition, the increase of efficiency in port operations through CTP reduces fuel consumption and GHG emission from trucking operations (NWSA, 2021i). Trucking is the second-largest GHG emitter sector and is responsible for 27% of total GHG emissions generated from port-related operations within the NWSA boundaries (NWSA, 2021i).

4.4.3 *Barriers for Implementing Clean Truck Program*

The GHG emission reduction methods for trucking operations are existed but are limited (NWSA, 2021i). The only way to achieve substantial GHG reduction from trucking operations is repowering truck engines with low emission alternatives, such as electrification, hybridization, or utilizing alternative low carbon fuels. Alternative fuels, such as renewable diesel fuels, have a large potential to reduce GHG emissions from trucks, but Washington State has not adequate infrastructure network to power trucks with renewable diesel fuels (NWSA, 2018j, 2021i). Likewise, electric battery and hydrogen fuel cell model trucks have demonstrated for port operations, but the Puget Sound region has not been deployed a sufficient bunkering/charging network to support this transition (NWSA, 2021i). In addition, electric battery and hydrogen fuel cells do not represent a price parity with the diesel equivalents (NWSA, 2021i).

On the other hand, there have been regulatory efforts going on to support zero-emission trucks. The State of California adopted the California Advanced Clean Truck Rule, which aims to increase the number of zero-emission trucks available in the market (NWSA, 2021i). In 2021, The California Advanced Clean Truck Rule adopted by Washington State, which requires 40% of the sale of class 8 tractors (heavy-duty trucks that are demonstrated to port operations), must be zero-emission by 2035 (NWSA, 2021i). The CARB Advanced Clean Truck Rule Market Assessment claims that the battery-electric trucks will be cost-competitive against diesel counterparts by 2030 (NWSA, 2021i). In addition, along with the enactment of the Washington State Low Carbon Fuel Standard rule in 2023, the NWSA expects an increase in the availability of renewable low carbon fuels in the region (NWSA, 2021i). On the other hand, most of the trucks calling at the NWSA terminals are brand new trucks instead of second or third-hands; therefore, it is uncertain how the NWSA trucking operations will be affected by the recent development in zero-emission truck availability (NWSA, 2021i).

Accordingly, in the CTP implementation, the NWSA focuses heavily on reducing local air emissions from the trucking operations and utilizes operational improvement measures for trucking operations to reduce energy consumption and GHG emissions (NWSA, 2021i). After the 2007 standards, the EPA has not demonstrated remarkable truck engine emission standards to reduce GHG emissions, only fuel efficiency improvement standards for truck model engines between 2014 and 2017, aiming for a 3% decrease in GHG emissions (NWSA, 2021b).

Another technological barrier for the CTP implementation is that 2007-2010 model trucks are not well-designed for drayage duties due to Diesel Particulate Filter's (DPF) function, which induces high maintenance costs for truck owners. The port and other stakeholder agencies conducted training for truck companies aiming to reduce maintenance costs (NWSA, 2018j). The port offered a $500 voucher to truckers who completed PSCAA's video training associated with the DPF maintenance (NWSA, 2019g).

The 80% of truckers calling at the NWSA terminals were individual truck operators contracting with large trucking companies, which means that most of the trucks operating were people who have limited credit history and struggle to buy a new truck without financial support (NWSA, 2017b). Therefore, the progression of the CTP has been affected by various economic constraints, such as fluctuation in the funding availability (NWSA, 2019g). In addition, as mentioned in Chapter 4.1.3, due to uncertainties in the Clean Truck Program's deadline dates, PSCAA decided to allocate the DERA 2018 fund to another emission reduction project (NWSA, 2018e), which led port officials to spend a substantial amount of energy for seeking financing support for truck operators (NWSA, 2019g).

As noted above, the NWSA experienced problems identifying compliance deadline dates for the CTP implementation. Multiple scholars in the literature studied this issue. The outcomes show that miscalculations in designing the CTP implementations in the ports can adversely affect the functioning ability of truckers and result in a decrease in the port's cargo throughput handled (Bjerkan & Seter, 2019a). The NWSA's experience was similar, by the first identified compliance deadline for truckers, January 1, 2018, nearly half of the trucks calling at the NWSA's participating terminals was in non-compliant status (NWSA, 2018j), meaning that if the Clean Truck Program implementation deadline was forced at the beginning of 2018, many truck companies could have gone out of business, resulting in loss of 2000 family jobs, and the process could have led to a cargo diversion from the gateway (NWSA, 2018j).

The main dilemma in the identifying deadlines for the CTP was the caused inequity for both parties: truckers who were not able to afford new trucks and request more time and incentive, and truckers who invested hundreds of thousands in new trucks with increased maintenance costs and requested the NWSA to stick to designated deadlines to eliminate their competitively disadvantage position (NWSA, 2018e). Accordingly, partner agencies, including PSCAA and Washington Trucking Association (WTA), urged the NWSA not to exceed the designated deadline for keeping the program fair for truck operators who had a substantial investment in new trucks (NWSA, 2018k). In addition, the WTA representative claimed that if the NWSA does not implement the clean truck program voluntarily today, there will be needed stricter legislations in the future to achieve the zero-emission truck requirements (NWSA, 2018j). Besides partner agencies, truck companies that invested in the newer trucks stated their opposition to the extension of deadlines, referring to their increased maintenance cost by 80%, emphasizing that the dates were declared ten years ago (NWSA, 2018j). Thereafter, in April 2018, only %57 of the trucks calling at the NWSA participating ports was in compliant status for CTP, so the NWSA decided to allow the non-compliant trucks to pass through gates with a Temporary Access Pass, which was required a commitment to become compliant by the end of 2018; and the ultimate deadline was designated as January 1, 2019 (NWSA, 2018g).

4.4.4 *Conditions for Successful Clean Truck Program Implementation*

After the designation of January 1, 2019, as an ultimate deadline date for truckers to comply with CTP requirements, the NWSA launched financial incentives, strengthened the communication and engagement of all parties, and demonstrated new technical methods satisfying the CTP standards to accelerate the compliance process of the non-compliant truckers. In terms of financial incentives, the NWSA established the Clean Truck Fund (CTF), which provides loans with lower interest rates compared to the market conditions, to support truckers who have a limited credit history. The CTF was established under the management of the Community Development Financial Institution (CDFI) (NWSA, 2018h). The NWSA covered between 20 - 25% of CDFI's total funding pool to mitigate risk factors of providing market-rate loans for limited credit history participants (NWSA, 2018h). The total funding amount of the NWSA's CTF was about $2.8 million comprised of multiple sources, including Ecology's VW Grant ($1.2 million), NWSA's Capital Investment Plan (CIP) ($1 million), Ecology's Clean Diesel Fund ($234,000), PSCAA ($200,000), and the City of Seattle ($150,000) (NWSA, 2018i).

In addition to the CTF, the NWSA applied for the SCAQMD 2017 DERA grant, a partnership between the SCAQMD, PSCAA, and Oregon Department of Environmental Quality, aiming to modernize drayage trucks (NWSA, 2018f). After the update in truck engine model requirement in the San Pedro Bay ports, which obligates 2014 or newer model truck engines within port boundaries, Californian truckers refused to scrap their 2012 or newer model trucks (NWSA, 2018c). Since the truck engine requirement for Washington State was 2007 or newer, SCAQMD decided to sell these 2012 or newer model trucks to the Washington State truck owners with a price far below their market value. However, due to the program's complexity, 40 truck operators applied for the SCAQMD grant, but only 12 of them could provide requested documents, and only 8 of those participants were allowed to purchase 2012 model trucks (NWSA, 2019g).

The NWSA also adopted Seaport Truck Scrappage and Replacement for Air in Puget Sound (ScRAPS) program in collaboration with PSCAA to support truckers economically (NWSA, 2018e). The conditions for being eligible for the ScRAP incentives are to make at least 200 trips to the NWSA terminals per year and 50% of these operations take place within the Washington State borders (NWSA, 2018h). The incentive reimburses up to 50% of the cost of the new truck up to $27,000, and the old truck must be scrapped (NWSA, 2018h). Beside financial incentives, the NWSA also demonstrated LNG, biofuel, and hydrogen retrofit options, as long as their emission reduction capacity accommodate the EPA's 2007 truck engine emission standards, to support truckers who could not afford a new truck since a used truck comply with CTF requirement costs between $35,000 and $100,000, while retrofit costs range from $10,000 to $25,000 (NWSA, 2018h).

The truck operators stated that their main priority was improving efficiency in terminal operations to make more turns since they were paid based on the number of turns they have done, instead of the time they spent at terminals (NWSA, 2018e). In addition, large trucking companies are charged to pay high fees due to queuing-associated delays (NWSA, 2019f). To address these concerns, the NWSA invested in technological infrastructure improvement of the terminal gates to decrease congestion and idle time (NWSA, 2018e). The technological improvements in terminal infrastructures include installing radio frequency identification (RFID) systems, which are used to track truck activities and share real-time data with port stakeholders to optimize their operations (NWSA, 2018e).

At the beginning of the implementation, there were two monitoring options for the NWSA: Open Standard (STD) Passive RFID and WhereNet RFID (NWSA, 2018f). Both options have their own advantages and drawbacks. For example, STD RFID is compatible with the Washington State Department of Transportation's Good to Go! System that makes it far cheaper than the WhereNet due to capital costs. However, the establishment period of the infrastructure of the technology takes too much time and requires additional developments in the Terminal Operating Systems (TOS) and Gate Operating Systems (GOS) (NWSA, 2018f). In addition, terminal operators had no experience with STD RFID technology (The Northwest Seaport Alliance, 2018c). The WhereNet option is more appealing when it comes to accommodating familiarity with terminal operators (NWSA, 2018f). The WhereNet RFID technology is used in all major port terminals on the West Coast (NWSA, 2018f). Moreover, WhereNet is compatible with TOS and GOS, meaning that WhereNet RFID requires less alteration in concession agreement updates (The Northwest Seaport Alliance, 2018c).

However, the complexity of the CTP implementation confused the truck operators since the program accommodated multiple financing options, and each fund had its unique conditions (NWSA, 2019g). At this point, the NWSA received regulatory support that clarified the authority of the port district to utilize both ports' capital and state funds into emission reduction projects, which increased the NWSA's control over the resources and resource allocation processes which reduced the program's complexity (NWSA, 2019g). In 2018, Representative Jake Fey presented the HB 2601 bill, which mandates trucks calling at the NWSA's both international and domestic terminals to have a 2007 or newer model engine by January 1, 2019. In addition, the bill aimed to enforce zero-emission engines for trucks by 2035. The NWSA opposed the bill referring to the PSEI results as proof for the success of the voluntary CTP implementation. Moreover, instead of applying state obligations, utilizing a voluntary effort presents a proactive image for the NWSA (NWSA, 2018j).

To sum up, the key components that brought success to the CTP implementation were addressing truckers' financial needs by establishing flexible fund programs, utilizing technology and data management, and proactive engagement with diverse groups of stakeholders (NWSA, 2019). The rate of compliant trucks calling at participating terminals was 49% in August 2017, increased by 14% by May 2018, reaching 63%, and made it 100% in March 2019 (NWSA, 2019g). After the implementation deadline, one-third of the trucks calling at the NWSA terminals was 2012-2013 models (NWSA, 2019g). In addition, $1.1 million from VW Grant and $138,000 from Ecology's Clean Diesel Grant left to remain in the Clean Truck Fund (NWSA, 2019g). This remaining money is considered a good signal for regulatory agencies to indicate that the port will continue investing in emission reduction projects (NWSA, 2019g). The number of trucks called in March 2019 was 3800, which is identical to the number measured the previous year at the same time (NWSA, 2019g), and The NWSA was the only port that successfully carried out a clean truck program among other ports in the US (NWSA, 2019g). The NWSA's achievements had widespread media coverage and presented a model for other ports, which strengthened the NWSA's corporate image and leadership in sustainable port efforts (NWSA, 2019g).

Chapter 5. CONCLUSION

In this article, we conducted a descriptive case study of the NWSA to explain port's GHG emissions reduction approach and factors influencing their adoption and success. Our findings from the ports' publicly available data showed that the factors influencing the NWSA's approach coincide with the given factors in the literature. Two primary drivers are highly influential on port decisions: the risk of cargo diversion due to increasing operational costs caused by the GHG emission measures and having limited control over the majority of the port-related GHG emissions. To overcome competitive pressures and legal constraints, the NWSA employed an aggressive external fund application policy and utilized concession agreements with the terminal operators to mitigate the most emitter sectors' emissions, OGV and trucks. In addition, the NWSA aligned its OPS projects with terminal modernization projects and took advantage of the hydropower-generated electricity of Washington State to promote the competitiveness of the OPS projects in the external funding applications.

Although the NWSA put a great effort to strengthen its relationships with the external stakeholders, including business partners, regulatory agencies, and funding agencies, we did not observe a remarkable public pressure from near-port residents, regulatory agencies, business partners, or internal stakeholders, meaning that preempting a voluntary air emission implementation worked for the port for now.

Our findings also showed that the NWSA is heavily affected by Californian port's GHG emission-related implementations. California ports host 25 times more vessel calls than Washington State and both states' ports are usually on the same string these vessels were assigned. Therefore, the NWSA was able to take advantage of the technological spill-overs of California's environmental regulations without imposing the same in their ports. Also, the NWSA adopted the proven application and technologies utilized by the California ports and did not bear the risk of being an early adopter.

In 2021, the NWSA and three participating ports renewed the NWPCAS framework and set new ambitious GHG targets. Moreover, the NWSA established strong signals by publishing its well-prepared 2021-2015 NWPCAS Implementation Plan for its internal and external stakeholders, pointing out that it will continue to implement sustainable port practices.

Future research should examine the impact of “coopetition”-related factors. Although strategic shipping company alliances and their relationship with sustainable development have been studied by many scholars, coopetition is still a new concept and the NWSA is an example of how “coopetition” impacts a port’s GHG emission reduction approaches. Furthermore, future research should focus on the effectiveness of the NWSA GHG emission reduction strategies. OGV Transit and Maneuvering are responsible for 41% of the total GHG emissions from the NWSA. However, we did not come across remarkable evidence for port preparing to address this sector even though the San Pedro Bay Ports have been implementing slow-steaming to reduce shipping emissions in transit and maneuvering successfully.

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