Chapter 12
Green Ports

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Abstract Sustainable shipping involves not only ships but ports as their extension. This chapter examines the issues associated with a green port operation. These include technologies such as cold ironing; market-based practices such as differentiated fairway dues, speed reduction, and noise and dust abatement; and others. The legislative framework in various countries is explained, and various environmental scorecards are discussed. This chapter starts with a brief review on recent academic research in the field of environmental management of ports and presents the status quo in leading ports around the world. The chapter emphasizes on the implementation of speed reduction programmes near the port, the use of cold ironing at berth, and the effects of fuel quality regulation, considering the perspectives of the port authority and the ship operator. The emerging environmental and economic trade-offs are discussed. The aim of this chapter is to be a starting point for researchers seeking to work on green ports. Insights of this chapter may also be useful for stakeholders seeking to select the best emissions reduction option depending on their unique characteristics.

Abbreviations

AGV	Automated guided vehicles
AMP	Alternative marine power
BPA	British Ports Association
CO	Carbon monoxide
CO_2	Carbon dioxide
ESPO	European Seaport Organization
ETS	Emissions trading system
EU	European Union

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IAPH	International Association of Ports and Harbors
IMO	International Maritime Organization
ITS	Intelligent transport systems
LNG	Liquefied natural gas
NO_x	Nitrogen oxides
OPS	Onshore power supply
POLA	Port of Los Angeles
POLB	Port of Long Beach
RMG	Rail mounted gantry
RTG	Rubber-tired gantry
SO_x	Sulfur oxides
UNCTAD	United Nations Conference on Trade and Development
VSRP	Vessel Speed Reduction Programme

1 Introduction

Shipping is considered the most efficient mode of transport in economic and environmental terms. Due to economies of scale, it can offer the lowest cost per ton-km transported. The sector's contribution to global CO_2 emissions accounted for 2.2% in 2012 (Smith et al. 2014) down from 2.7% in 2007 (Buhaug et al. 2009) for international shipping. In absolute terms, the CO_2 emissions were reduced from 885 million tonnes in 2007–796 million tonnes in 2012 (Smith et al. 2014). At the same time, maritime transport moves approximately 90% of the world's trade, with increasing trends for transported cargo volumes.

However, its impacts on climate change through greenhouse gas emissions and on human health from air pollutants released near residential centers cannot be ignored. Over the last decades, regulatory bodies have been developing policies that seek to further improve the sector's environmental performance, and at the same time, new technologies improve the efficiency of vessels. Operational practices of ship operators and port authority initiatives are also relieving the sector's impacts.

While there has been significant research on the environmental impacts of maritime transport, there has been relatively little work focusing on the effects of maritime activity in the proximity and at ports. The majority of academic research in the environmental impacts of maritime transport has focused on its overall contribution. However, effects near ports have not been extensively researched, with the majority of relevant studies being technical reports of port authorities focusing on a very broad level of environmental concerns.

1.1 Background

Ports are areas on a shore or coast that contain one or more harbors where ships can call and transfer cargo or people to and from the land. Ports serve as intermodal nodes connecting water and various land modes while also providing other useful services such as shipbuilding, maintenance, and bunkering facilities to the maritime industry. Each port has unique characteristics in terms of operation, layout, volumes handled, geography, and organizational structure. Classification can vary according to the aforementioned characteristics. Alderton (2013) classifies ports into major groups by function (cargo interface, ship/shore interface) or geography (coastal, tidal, artificial, inland, and river). Classification can also be based on size and capability to handle large ships. This chapter will focus on container terminals and their implications to the environment.

1.2 Main Terminal Types and Overall Growth of the Sector

Terminals are essentially facilities within the port that provide several berths to handle vessels and the exchange of cargo goods and/or passengers. A port may have many terminals of different types (and sizes), and each terminal has a primary operator that is in charge of the various operations and is under the control of the port authority. Terminals comprise of the wet and dry infrastructure, superstructure, cargo handling equipment, and human resources for its operations. The wet infrastructure is defined as the harbor basin where one or more berths are in place to receive vessels. The storage area pavement, the roads inside the terminal, and the foundations for the crane tracks and drainage systems are part of the dry infrastructure. The superstructure is referring to the buildings, sheds, and all other covered storage spaces within the terminal. Cargo handling equipment and human resources vary depending on the terminal type and size. The main terminal types can therefore be distinguished into the following:

- Ro-Ro terminals
- Liquid bulk terminals (LNG, crude oil, chemical products)
- Dry bulk terminals (grain, coal, ore)
- Ferry terminals
- Multipurpose terminals
- Container terminals

For all terminal types, there are some services that are common; these include the loading/unloading of vessels, the temporary storage of cargo in the terminal, the processing of cargo (certain types), and the loading/unloading of cargo to the next transportation stage (e.g., before moving to the hinterland). From an environmental perspective, the emission intensity of each activity varies. However, in line with the continuous growth of seaborne trade (as seen in Fig. 12.1), ports are also increasing in size in order to handle the additional throughput and cater for larger vessels calling. Figure 12.1 presents the growth of international seaborne trade during the last decade as reported from data of UNCTAD.

This continuous growth has resulted in larger vessels being constructed and the requirement for ports to handle additional throughput each year. In 2006 the Emma Maersk was introduced as the largest containership ever built with a maximum capacity of 14770 TEUs. Eleven years later the largest containership was the OOCL

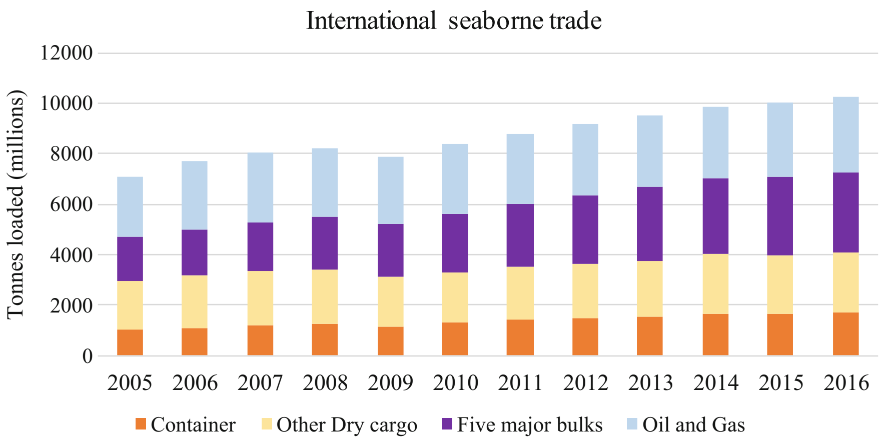

Fig. 12.1 Growth of international trade in recent years. (Data source: UNCTAD 2017)

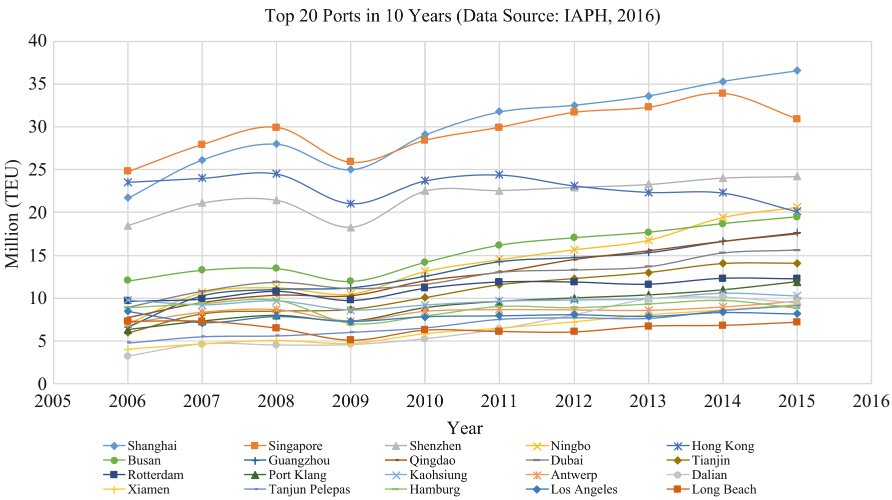

Fig. 12.2 Annual throughput in the top 20 container ports in the world (Data source: IAPH 2016)

Hong Kong with a capacity of 21413 TEUs. Such vessels cannot call at all ports, and as a result port authorities need to invest in additional dredging operations and install ship to shore cranes capable of handling such vessels. Along with the growth of the sector, and the introduction of bigger vessels, container terminals are every year required to handle larger volumes of containers. This is depicted in Fig. 12.2, where the growth in port throughput for the 20 biggest ports in the world is shown.

Figure 12.2 shows that for the majority of the biggest container ports in the world, the handled throughput was increasing between 2006 and 2015, with a notable exception of Hong Kong that has lost volumes, and the 2009 year which showed a drop for all ports, in line with the reduction of the maritime sector due to the financial crisis of 2008. The additional volumes handled will result in a higher environmental burden in the local environment, and it is important that port authorities create green agendas to reduce the negative environmental impacts of their growth.

1.3 What Is a Green Port

Passet (1979) proposed a three-pillar framework of societal, economical, and environmental development to describe sustainable development. The World Commission on Environment and Development (1987) defined sustainable development as meeting the needs of the present, without compromising the ability of future generations to meet their own needs. In transportation, the term sustainable or green transport is also based on a similar framework whereby the right balance of environmental, societal, and economical performance is sought after. Greene and Wegener (1997) note the importance of emissions, fatalities due to accidents, as well as the importance of satisfying the transportation demands of modern economies. Davarzani et al. (2016) conduct a bibliometric analysis on research related to green ports and maritime logistics but do not provide a definition for a green port. Nikitakos (2012) proposes the zero-emission port where any energy consumption within the port's operations is to be covered by in-port renewable energy sources (RES) generation, for example wind turbines or a small photovoltaic park. Arguably, a definition of a green port as being a zero-emission port is very exclusive as the energy demands of ports are quickly increasing with port throughput. In the context of this chapter, a "green port" is a port that has either developed a strategy to reduce emissions, energy consumption in their operations, and water pollution or has invested in new technology with improved environmental performance and in short is trying to become a "greener" port.

1.4 Structure of the Rest of This Chapter

The next section of this chapter presents recent research in academic literature in the field of green ports, ways of measuring the environmental performance, and the basic port operations that have an impact. In the third section, relevant legislation that may affect port performance from the IMO, the EU, or other regulatory bodies is discussed. The fourth section presents a summary of the different options port authorities may select to improve their environmental performance. The chapter concludes with the need for additional academic research in order to optimize the performance of said options.

2 The Environmental Angle of the Port System

The impacts of port operations on the surrounding area can be attributed to three main categories: maritime operations, in-port operations, and generated traffic outside the port's gates. The mechanisms through which each of these contributes to the environmental footprint of a specific port differ in each case, as do the potential mitigation measures. Due to the size of marine engines operated on board for propulsion and electricity requirements of each vessel, the fuel consumption of a large ship can result in massive emissions in each phase of the journey. Of particular concern are the emissions near the shoreline, as the generated emissions of marine engines contain pollutants with severe health effects. Certain port authorities monitor the emissions from each type of operations. Perhaps the most noteworthy example is the Port of Los Angeles (POLA) and its annual emissions inventory. Figure 12.3 presents the breakdown in the busiest container port of the USA.

It is evident that for pollutants with a local environmental impact, ocean going vessels (OGV) are by far the highest contributors with the notable exception of carbon monoxide (CO). It is interesting to notice that despite the very low sulfur limit allowed within the port due to environmental regulations from CARB, and the designation of the US ECA zone, in terms of SO_x emissions, the OGV are still the highest contributors at 93.5% of the total. Cargo handling equipment is the highest contributor in CO terms, which can be attributed to extended times of idling at a port that results in incomplete combustion in the diesel engines powering this equipment. Finally, heavy duty vehicles are the most important contributor in CO_2 terms and an important part of NO_x emissions. Not surprisingly, Californian ports have placed a lot of attention in reducing emissions from trucks, as California has had several problems with very high NOx emissions.

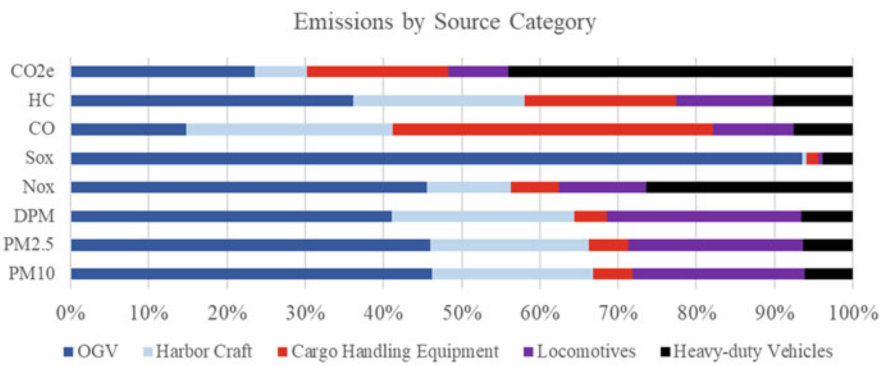

Fig. 12.3 Emissions breakdown by source in the Port of Los Angeles in 2016. (Data source: POLA 2017)

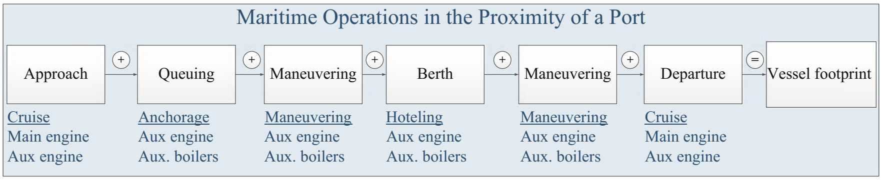

Fig. 12.4 The maritime operations of a vessel calling at a port and the machinery operating during each activity phase

2.1 *Maritime Operations*

For the construction of emissions inventories, the vessel activities near and at the port that are of interest include the approach, maneuvering, hoteling, and departure. These activities are shown in Fig. 12.4 along with the type of machinery that is operating during each phase.

Summing over all activity phases and their respective fuel consumption for each vessel calling at a port will result in an estimation of the environmental footprint of the maritime operations of the port. Such data can either be provided by a port authority or AIS data services that collect the position and speed of vessels. The main activity can be described by the pattern of vessel arrivals at the port and the duration of berth at each call. Ports tend to publish reports on their short-term expected traffic, patterns which combined with a comprehensive dataset of visiting vessels and berth durations could be used to obtain a thorough analysis of emissions within a port. In the event that these data are not retrievable, ship arrivals are usually modeled through Poisson processes which provide a good fit (El-Naggar 2010).

2.2 *Yard Operations*

Once a vessel is at berth, a number of operations take place at the port for the loading and unloading of cargoes and the embarkation/disembarkation of passengers depending on terminal and vessel types. When it comes to Ro-Ro terminals, vehicles need to quickly move from the ship to the yard and vice versa, while trailers need to be moved via either specialized yard equipment or via a truck-trailer combination. The yard operations are more complex in the case of container terminals due to the requirement for much more yard equipment. A typical layout of a container terminal and the three main areas of containers exchange is shown in Fig. 12.5.

Stopford (2009) defines the quayside as being comprised of several berths each serviced by one or more ship-to-shore (quay) cranes able of lifting containers weighing up to 40 tons. These cranes are generally rail mounted to move along the quay for positioning at the required place with respect to the berthed ship. They

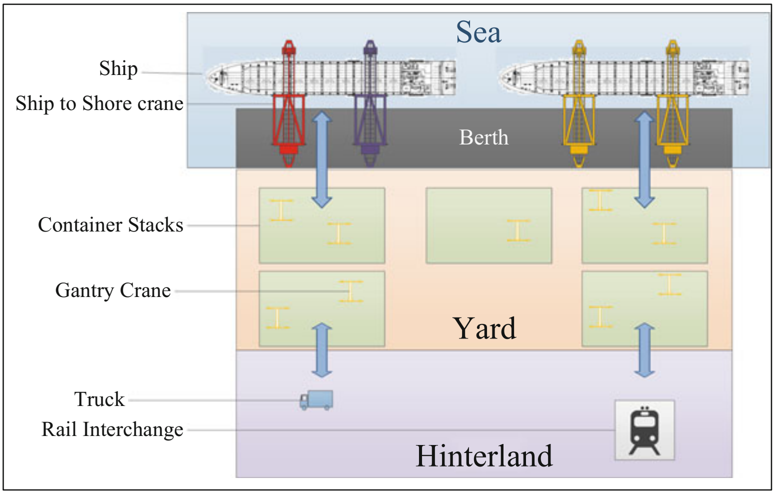

Fig. 12.5 Container terminal layout. (Adapted from Zis 2015)

are classified by lifting capacity and the maximum size of a container ship they may handle. The main categories are Panamax cranes which can handle a ship of 12–13 containers wide, the post-Panamax (18 containers), and the super-post-Panamax which have a reach that reaches 25 containers to handle the largest containerships. A super-post-Panamax crane may weigh up to 2000 tonnes and cost up to 14 million USD (Port Everglades bought three such cranes for a total of 41.4 million in June 2017). Due to the vast weights of the cranes, the quay needs to be strengthened to tolerate loads. Quay cranes can be the cause of a major bottleneck in the terminal's operation slowing down fast ship handling operations and increasing turnaround time (Imai et al. 2008). As technology improves, the quay cranes become faster able of lifting two containers at the same time and increase the number of maximum moves per hour. Energy efficiency also increases by taking advantage of hybrid technologies and energy regeneration when the cargo is lowered.

Container terminals require large storage spaces for the containers which may stay at the port several days. The stacks where the containers are placed ideally should be near the berth for fast unloading of the vessel. This area is typically called the yard where containers are stored in multi-tiered stacks which for ports with very limited area resources can reach up to 12 container tiers (e.g., Hong Kong). The transportation between the quay and the yard differs from port to port depending on size, throughput handled, and resources available. The most common machinery used are forklift trucks, reach stackers, chassis-trailers, straddle carriers, and automated guided vehicles (AGV). These vehicles pick up the container once the quay crane has unloaded it from the vessel (in the chassis and AGV case, the container is placed on top of their platform) and move it close to the storage stacks and vice versa for outgoing containers. Cargo handling equipment is required for the horizontal and vertical movements of containers at the stack (reshuffling of containers). The typical machinery involves:

- Rubber-tired gantries (RTG) which are flexible but cause high loads on the pavement.
- Rail mounted gantries (RMG) that are more appropriate for larger stacks but are more expensive.
- Automated stacking cranes, which are expensive to acquire and maintain, reduce labor costs.

Containers that are destined for the hinterland will have to be moved from the stacks in the storage yard to the stacks in the hinterland side before being boarded on the locomotives or heavy goods vehicles. These movements inside the yard are usually performed by stacking cranes. Energy losses are often observed due to relocation of containers or inefficient transportation due to congestion problems in the yard (Steenken et al. 2004). There has been significant research that aims to minimize the number of shuffle movements of containers at the yard, as well as on inland intermodal terminals facing the same problem (Colombaroni et al. 2017).

2.3 Hinterland Side

The final (or first process) occurs at the gate where export containers leave the port for their inland destination while import containers arrive, respectively. The busiest terminals use advanced information technology to reduce congestion at the gate and waiting times for trucks. As shown earlier in Fig. 12.3, the operations at the gate are a very significant contributor in most pollutant species generation.

In all of the aforementioned processes where containers are moved, significant energy is required. The source of this energy varies depending on the equipment used and whether this consumes fossil fuel (e.g., diesel engines), relies on electricity provided by the grid, or is a hybrid system. An estimation of the energy needs can be performed through analytical calculations based on the horizontal and vertical movements of containers from one place to another inside using basic energy models (equipment specifications, mass of container, speed of movement, and height differences are necessary inputs) or using simulation tools. The next section summarizes the main environmental challenges that ports are facing nowadays.

2.4 Environmental Challenges in Ports

The negative environmental effects of port operations are increasing with the growth of handled throughput. Port operations have both direct and indirect environmental impacts that regulators, shippers, and port authorities have been trying to address in recent years. The major environmental impacts are air and water pollution, depletion of fossil fuel due to the energy requirements of port operations, noise, and optical intrusion (Talley 2009).

Discharge of ballast water, dredging operations at the port, waste disposal, and oil spillage may all contribute in water pollution near the port. Large vessels carry massive amounts of water in their ballast tanks that is used to stabilize the ship. When cargo is removed, the ship pumps in water to compensate for the change in cargo weight distribution. When the cargo is loaded, the ballast water is discharged. The environmental concerns with ballast water treatment occur when it is discharged in different areas (pumped in in one port, released in a different port); it can lead to the unintentional invasion of nonindigenous species. These microorganisms can damage aquatic ecosystems and create health issues (Mooney 2005). A similar problem may occur with the transportation of nonindigenous through hull fouling of a vessel (Drake and Lodge 2007). The aquatic environment can also be negatively affected when dredging operations to increase the port's depth are taking place. Finally waste generated onboard a vessel has to be disposed in non-harmful ways, and ports are expected to be able to provide waste disposal solutions. Oil spillages can occur anywhere along the journey of a vessel including near the port with severe environmental consequences.

The visual intrusion or aesthetic pollution is the result of the vessels, cargo handling equipment, and port superstructure altering the appearance of the environment around the port. Together with the noise generated during port operations, and the lighting pollution during night-time operations, these have a severely negative effect on nearby residents particularly in terms of sleep deprivation and increase of stress. Noise is a serious concern these days for transportation, with a particular focus on noise from airplanes. Various strategies have risen to address the issue of noise from airport operations. For example, alterations in the approach of aircrafts to the airport, steeper descents to minimize exposure to residents, and adaptation of new technologies on the aircraft engines have been utilized. Parallels to the maritime sector exist; however, for ports the main source of noise pollution is the yard and hinterland operations and not so much the vessels themselves. A very different environmental concern for port operations is the effects of noise to marine mammals from maritime transport.

Air pollution in ports is the result of vehicle and cargo movements (ships, cargo handling equipment) and has both local and global consequences. Various different pollutant types are emitted, some of which affect the local air quality, while others are climate change forcing agents. Currently dealing with air pollutants is the most pressing issue port authorities, shippers, and regulators are trying to address with the majority of existing policies and port initiatives. The next section conducts a literature review on academic studies in the field of environmental impact of ports, focusing mainly on emissions.

2.5 *Emissions in Ports in Academic Literature*

A limited number of studies have specifically focused on emissions in ports and their surrounding regions. The review of Davarzani et al. (2016) suggests that the topic of green ports is at a very early stage, but it will continue to grow as practitioners and governments continue to face challenges that research can solve. There are various academic studies that construct emissions inventories in specific ports. Saxe and Larsen (2004) modeled NO_x and PM emissions in three Danish ports. They also model the dispersion of the pollutants and the maximum concentrations in nearby areas using meteorological air quality models. Marr et al. (2007) used a network of emissions monitoring stations in the harbor of Aberdeen to identify the most important pollutants and create an emissions inventory in the area for all transport activity. For ship emissions (mainly ferries), they sampled emissions from the ship funnels to model emissions.

De Meyer et al. (2008) use a bottom-up activity-based model to estimate emissions from international shipping in the Belgian part of the North Sea and four major Belgian ports. They compare their results to the national inventories of CO_2, SO_2, and NO_x emissions in Belgium and find that for the latter two, the contribution is very high (30 and 22%, respectively). Liao et al. (2009) compare the CO_2 emissions generation from trucking transportation with intermodal coastal shipping that incorporates in-port emissions in Taiwan. They show that a shift toward maritime modes will lead to carbon emissions reduction. However, they do not consider other pollutant species in which the maritime sector is less eco-friendly.

Tzannatos (2010) constructs an emissions inventory for NO_x and SO_2 in the port of Piraeus using a bottom-up approach with average load factors for each ship activity mode. He concludes that the port of Piraeus is responsible for 1.2 and 2.5%, respectively, of the total national transportation contribution in Greece. He also calculates the external costs of emissions and concludes that the majority of these are stemming from coastal passenger shipping due to high speed ferries. Berechman and Tseng (2012) construct comprehensive emissions inventories for all ship types and trucks in the port and conclude that tankers, container ships, and bulk carriers are the most polluting ship types. Ng et al. (2013) created an emissions inventory for the port of Hong Kong, based on AIS data for ship movements. Song (2014) did similar work for the port of Yangshan in Shanghai and additionally evaluated the social costs of ship emissions near the port. More recently, Dragovic et al. (2018) focused on near-port emissions from cruise vessels and arising externalities in the cruise ports of Dubrovnik and Kotor. Cullinane et al. (2016) used a bottom-up methodology to estimate emissions at berth from containerships in Taiwan and suggested emissions reduction actions to quantify their potential.

Regarding yard operations, the majority of academic literature is focusing on simulation of said operations or in optimization problems. For more information on the current status of in-yard operations on container terminals, the seminal literature paper of Steenken et al. (2004) provides a good overview of OR problems. Carlo et al. (2014) conduct a more recent literature review focusing on storage yard operations and suggest new research topics. There are certain research papers that focus on the interchange between quay and yard, focusing mainly on berth scheduling and quay-crane allocation. Zhou and Kang (2008) minimize the waiting time of vessels at berth in a stochastic environment. Zeng and Yang (2009) utilize a hybrid simulation/optimization approach for the container scheduling problem in yard operations considering quay and yard cranes. The seminal work of Golias et al. (2010) maximizes berth productivity and considers fuel consumption and arising emissions from vessels at berth. On purely yard operations, Angeloudis and Bell (2010) present a dispatch algorithm that minimizes delays of AGVs and increases port productivity, which will have indirect environmental benefits due to the minimization of energy consumption at the yard.

On the hinterland side, most papers focus on ways of minimizing queues at the gates or contemplate reward systems for booking slots. Aregall et al. (2018) recently conducted a literature review that focuses on the landside of port operations. Their paper is among the first to present the current status of green agendas in ports around the world with a focus on hinterland operations and categorize common measures as technological, infrastructure, or monitoring of activities. Chen et al. (2013) reduce truck emissions at the terminal by optimizing the arrival patterns. Of course, an improvement in one type of operations may result in benefits in other areas as well. Zhao and Goodchild (2010) show that by relieving bottlenecks caused at the port's gate through improved planning, the turnaround time of vessels can also be reduced.

Cao and Golias (2013) evaluated the effects of gate strategies on emissions reductions at marine container terminals. They developed a traffic simulation model capable of measuring the impact of various gate strategies on congestion at terminal gates. The proposed model was used to quantify both travel time and delay, and emission levels at terminal gates before and after gate strategies have been implemented. Each terminal was modeled as a series of tolls that were part of the network. This approach allowed a more accurate estimation of entrance and exit gate delays, equipment inspection delays, and wait time before the gates open and lane restrictions.

This section presented the main environmental problems that port operations are causing and showed the main research areas seeking to address these problems. The next section of the chapter will present the relevant regulation that affects port operations.

3 Relevant Regulation

In response to the growing concerns on the environmental impacts of transportation, a number of regulations and policies have been developed. This section presents the most important legislation affecting port operations. The most important associations of port authorities and their efforts are also discussed to set the scene for necessary research in the coming years in the field of green ports.

3.1 The International Maritime Organization

The primary regulator of maritime transport is the International Maritime Organization (IMO). In 1973 the IMO formed the Marine Environmental Protection Committee (MEPC) to address matters concerned with marine pollution. In the same year, MEPC adopted the International Convention for the Prevention of Pollution from Ships, known as the MARPOL Convention. Its aim is to prevent air pollution and address sewage, waste, garbage, and oil spillage and is applied to 99% of the world's merchant tonnage. The MARPOL Convention has been amended by two Protocols in 1978 and 1997. In this book, oil pollution is discussed in Chap. 5.

Emission Control Areas (ECAs) and in particular Sulfur ECAs (SECAs) are discuss in Chap. 7 of this book. From a port authority's perspective, the designation of SECAs is something that will result in less emissions during the approach and departure of the vessel. During the hoteling activities of the vessel, typically MGO or MDO is used from the vessels that are low on sulfur. However, in theory the SECAs could result in a loss of throughput for the ports, as some ship operators may opt to call at ports that are not within a SECA.

3.2 European Union

The European Union has long considered ports as vital for economic growth. In 2012 74% of the European trade was shipborne (ESPO 2012), while Eurostat estimates that 37% of the total intra-EU exchange of goods passes through some of the EU ports. Despite the importance of the port sector, the EU faces significant challenges including bottlenecks due to hinterland congestion and investment requirements to accommodate future growth. The environmental implications of sulfur in fuel in Europe were first considered through the Directive 93/12/EEC of March 1993 which regulated the sulfur content of certain liquid fuels. The Directive prohibited marketing of fuel up to 0.2% and 0.05% sulfur content (by weight) for fuel in all transport modes by October 1994 and October 1996, respectively. Vessels sailing between a member state and a third country were excluded from this regulation.

In 1999 this directive was amended through the Council Directive 1999/33/EC which essentially changed the limit of sulfur to 0.1% by the year 2008. The amended Directive required for the first time that from January 2003 heavy fuel oil with sulfur content exceeding 1% would be banned from use within the territory of a member state. The Directive would provide a period of no more than 6 months with a higher limit of sulfur for certain member states. These are the ones that could not apply the limits due to complications in the supply chain of crude oil and petroleum products.

The first effort of the EU to specifically address sulfur emissions from shipping came through Directive 2005/33/EC. It acknowledged the importance of the SO_x ECAs designated by the IMO and placed a limit of a maximum of 0.1% sulfur by weight fuel used by inland waterway vessels and ships at berth in community ports. Furthermore, it banned the use of heavy fuel oils exceeding 3% sulfur content in the territorial seas of each member state. Territorial waters are defined internationally as 12 nautical miles from the baseline of a coastal state under the 1982 United Nations Convention on the Law of the Sea – UNCLOS.

Placing sulfur limits within inland waterways and on vessel activity at berth signifies how important the EU considers the SO_X emissions to be near residential areas. In order to ensure proper use of fuel, the Directive requires all fuel switching operations to be recorded in ships' logbooks. In addition, the Directive allows the use of either shoreside electricity while at berth or alternative emission reduction technologies that would result in at least equivalent reductions to those achieved with the use of low-sulfur fuel. While there is currently no cold ironing targeting regulation, the 2005/33/EC as well as the will of the EU to promote the use of renewable energy sources should facilitate the use of AMP in European ports. An additional step was Directive 2014/94/EU that stipulates that from the 31st of December 2015, all EU ports will be required to have some capability of providing shore power.

3.3 California Air Resources Board (CARB)

The California Air Resources Board (CARB) is a part of the California Environmental Protection Agency and was setup in 1967 to attain and maintain healthy air quality. California had arguably the worst air quality and the highest levels of air pollution due to the largest number of cars in the USA. The two largest container terminals by volume in the USA are the ports of Los Angeles (POLA) and Long Beach (POLB). CARB has developed regulations targeting specifically transport activity in these ports. While the coasts of California are in the North American ECA, there were already stricter limits in place for maximum sulfur fuel content allowed for OGVs. There were two phases in the fuel requirements for OGVs in California. Phase 1 had an upper limit of 1.5% for MGO and 0.5% for MDO effective from July 2009 which would then be changed to 1% and 0.5%, respectively, from August 2012 (CARB 2012). The regulation in lieu (Phase 2) became effective in January 2014 and restricted the use of fuel with sulfur content by weight exceeding 0.1% by any machinery onboard a vessel within 24NM of the Californian coast.

The fact that both POLA and POLB are under the same regulation facilitates the operation of the ports. CARB has also promoted the use of alternative technology and in particular the provision of shore power. In 2007 the "Airborne toxic control measure for auxiliary diesel engines operated on Ocean-Going Vessels At-Berth in a California Port" Regulation (widely known as At-Berth Regulation) was approved. The regulation targets passenger, container, and refrigerated cargo ships berthing in any of the Californian ports. It currently dictates that ships must reduce by 70% the at-berth emissions from auxiliary engines for at least 70% of their calls in

Californian ports. This can be achieved either by turning engines off and connecting to other source of power or by using alternative control techniques that achieve similar reductions for PM and NOx emissions. It applies to POLA, POLB, and the ports of Oakland, San Diego, San Francisco, and Hueneme, for fleets with more than 25 annual visits (more than five for passenger vessels). This percentage will increase to 80% by 2020.

An important challenge with regard to AMP is the difficulty of accessing the AMP-ready berth which can already be in use by another vessel. Fleets are not in control of their allocated berths, while there are still compatibility issues faced between the dock facility and the ship. For some ship owners, the use of alternatives to shore power may be preferable economically as an emissions reduction method considering retrofitting costs for the vessel.

3.4 Port Associations

There are various port associations globally with the task of representing port authority members, the most famous of which is the International Association of Ports and Harbors (IAPH). Others include the American Association of Port Authorities (AAPA), the European Sea Port Organization (ESPO), and the British Ports Association (BPA). Such associations share the common objectives of representing their members, providing guidance toward more efficient operations and promoting the exchange of experience on successful green strategies developed by port authorities around the world. Unfortunately, the majority of objectives are monitored in a very qualitative manner usually revolving around the suggestion of good practice guides and are not backed by quantitative procedures to verify the potential in environmental improvement.

The IAPH has launched the World Ports Climate Initiative (WPCI) targeting GHG emission reductions for its members. The WPCI supports ports to monitor and reduce their CO_2 footprint through working groups that provide practical information on emissions reduction methods online. The IAPH has additionally designed a tool box that showcases successful implementation of port initiatives and clean air programmes for all operations taking place in a terminal. Finally, in March 2018 the IAPH launched the World Ports Sustainability Program to guide port members on how to achieve progress on the Sustainable Development Goals (SDG) of the United Nations (UN). The American Association of Port Authorities promotes the reduction of GHG from port-related activities and urges the need for IMO to set global standards for GHG emissions targets from vessels. The AAPA is also a strategic partner of the World Ports Sustainability Program.

The European equivalent of IAPH is ESPO that is also a strategic partner of the World Ports Sustainability Program. ESPO has developed the Self-Diagnosis Method (SDM) framework for port authorities within the EcoPorts network. A port in Europe or Norway may join this network by attaining the EcoPorts status as soon as its authority completes the SDM checklist. This is meant to provide insight on problematic areas within the port that should be prioritized for environmental improvement. ESPO has also published a green guide for the systematic port environmental management and designed the Port Environmental Review System (PERS). PERS complements the SDM and assists port authorities to introduce environmental management systems (ESPO 2012). EcoPorts members are expected to review their progress through the SDM checklist annually. The British Port Association (BPA) has adapted the ESPO environmental review and code of practice and holds annual meetings for the environmental managers of member ports. While tools such as PERS and the SDM are useful to provide a qualitative indication of improvement over the years, they are not sufficient. A quantitative estimate of actual reductions in energy use, emissions generated, or other environmental issues is necessary to ensure that each port is able of tracking its progress. This lack of quantitative evidence in the agendas of port associations around the world raises the issue of efficiently estimating, monitoring, and mitigating emissions near and at ports.

The main policies and regulations affecting maritime transport and its environmental impact were presented. However, there are also decisions that stakeholders may make which can also affect their emissions and environmental repercussions, even if the initial motivation is to minimize operating costs. The options span from rewarding clean practices of visiting fleet (either vessels or trucks in the hinterland) to major investments in equipment renewal with a focus on container terminals. These will be presented in the next section.

4 Toward a Green Port

This section will present the main options that ship operators, port authorities, and truck operators currently have at their disposal to improve their environmental performance.

4.1 Operational Practices

The first operational practice that has an impact on port operations was the constant increase in vessel sizes. Vessel sizes are increasing due to the arising economies of scale offering improved cost-efficiency per ton-NM (Cullinane and Khanna 2000). From a terminal operator's perspective, this means handling larger vessels but more containers per call. The energy intensity at the yard per call will increase (more cranes assigned to the larger vessels and more moves per call), while the vessel emits more in comparison to a smaller vessel. What is of interest is whether the ship emissions per TEU handled is lower. A simplistic calculation follows.

The fuel consumption during sailing in the proximity of the port (only main engines and auxiliary engines are active) is estimated by Eq. 12.1, while the fuel consumption FC_{berth} of a vessel at berth using auxiliary engines and boilers for its hoteling demands can be estimated using Eq. 12.2:

$$FC_{nearport}\,(\text{ton}) = 10^{-6}\,(SFOC_{main} \cdot EL_{main} \cdot EP_{main} + SFOC_{boiler} \cdot BP_{boiler}) \cdot \frac{D}{V_s} \tag{12.1}$$

$$FC_{berth}\,(\text{ton}) = 10^{-6}\,(SFOC_{aux} \cdot EL_{aux} \cdot EP_{aux} + SFOC_{boiler} \cdot BP_{boiler}) \cdot t_{berth} \tag{12.2}$$

Where

SFOC (g/kWh) is the specific fuel oil consumption of the machinery
EL(%) is the engine load at which the machinery operates
EP (kW) is the nominal installed power of the machinery
BP_{boiler} (kW) is the power demand of the boilers
D is the sailing distance from the port that we model
Vs is the approach/departure speed of the vessel
t_{berth} is the total time the vessel spends at berth.

Assume the vessels with the following technical specifications in Table 12.1 and that the maneuvering takes place in the first/last 1 NM from the port lasting 1 h in total. The distance of interest *D* is within 20 NM of the port, and for each vessel, it is assumed that 60% of its capacity is loaded and unloaded at the port (to estimate the time at berth). Under these assumptions, and using Eqs. 12.1 and 12.2, it is possible to estimate the total CO_2 emissions per call for each vessel. These are depicted in Fig. 12.6 broken down per activity phase (tonnes per call) and also per TEU handled (kg/TEU) at the port.

Figure 12.6 shows that as an individual call the ULCV emits more than the Panamax (particularly at berth where it spends more time), but broken down per TEU handled, the larger vessel is more efficient. From a terminal operator's perspective, this will mainly depend on the assigned number of cranes for each boat. In the example in this chapter, twice the cranes were assigned for the larger vessel, which had a more than three times TEU handling demand than the smaller vessel. If the number of cranes assigned was proportional, the ULCV would offer a further improved efficiency. Of course, this could lead in an increase of the total throughput handled at the port (more vessel calls per period) and thus increase its environmental impact in absolute terms.

The next operational practice of ship operators is the gradual fleet renewal where new builds are more fuel efficient. Their engines have a lower *SFOC* which reduces the total fuel consumption at each activity phase. The improved vessel designs will also result in reduced hydrodynamic resistances and thus lower *EL* or necessary *EP*. In recent years, the practice of slow steaming resurfaced due to the depressed market conditions and the relatively high fuel prices (until 2013). This practice has been proved to reduce CO_2 emissions despite the potential deployment of additional

Table 12.1 Technical specifications of containerships and port call/berth information

Vessel class	Technical specifications						
	EP_{main}(kW)	EP_{aux}(kW)	$SFOC_{main}$(g/kWh) at Vs	$SFOC_{aux}$(g/kWh)	EL_{main}(%) at Vs	EL_{aux}(%) at Vs	BP_{boiler} (kW)
Panamax	35,600	7800	178	220	85	30	525
ULCV	81,000	22,000	172	220	85	30	630
Vessel class	Port call berth information						
	V_s	Capacity (TEU)	Import/export traffic	Assigned cranes	Crane productivity (lifts per hour)	TEU factor	$FC_{maneuvering}$ (tonnes per call)
Panamax	17	5000	60%	5	25	1.7	0.92
ULCV	21	16,000		10			1.32

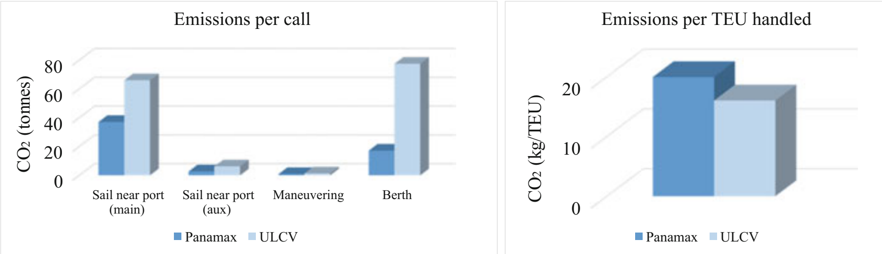

Fig. 12.6 Emissions per call for the two different classes and emissions intensity per TEU

vessels (Cariou 2011). Considering the benefits of a port, the slight change in operational speeds will have some positive impacts near the coastline, the extent of which will depend on the geography of the port and whether there is an extended period of low sailing during approach/departure.

4.2 Technologies

In terms of use of technology to improve the environmental performance of the port, the majority revolves around the electrification of the various operations and the gradual replacement of the use of combustion engines. On the maritime side, this concerns the use of shore power or cold ironing that connects vessels at berth with an electricity source and allows switching off the auxiliary engines. Zis et al. (2014) discuss the effectiveness of cold ironing as an emissions reduction option and construct a quantitative framework that allows an economic evaluation of the technology. This section will present the current status of cold ironing globally.

In California, six ports are affected by the at-berth regulation (see Sect. 3.3): the ports of Los Angeles (POLA), Long Beach (POLB), Oakland, San Diego, San Francisco, and Hueneme. The Port of Gothenburg in Sweden has two ferry (Ro-Ro) terminals with cold ironing capabilities. Shore power is supplied by local surplus wind-generated power and is marketed as a zero-emissions solution. Ferries have in general lower electricity requirements compared to other types, mainly lighting and ventilation during loading/unloading of vehicles (Zis and Psaraftis 2017). Therefore, the Gothenburg electrification process is much simpler than OGV in Californian ports. The port of Antwerp has provision for seven onshore power connection points at one terminal, for barges. In Hamburg, LNG barges are deployed that provide power to vessels at berth, a solution that is practically substituting MGO of auxiliary engines with LNG combustion. Zis et al. (2014) estimate that cold ironing can result in local emissions savings between 48% and 70% for CO_2, 3–60% for SO_x, 40–60% for NO_x, and 57–70% for BC of a container terminals ship emissions inventory.

Zis (2019) note that the low-sulfur regulation may actually be a barrier for cold ironing, as some ship operators may opt to invest in a one-off solution of installing scrubber systems with similar costs.

Scrubber systems are a technology mainly targeted to reduce SOx emissions and secure compliance with the SECA regulation. Vessels running on scrubbers will also emit less PM emissions, and while the scrubbers are running in the proximity of a port, the local emissions will be reduced (Zis et al. 2016). For some vessels, the scrubber systems are also operating during berth, but in general most vessels are using MGO at berth regardless of regulation for their auxiliary engines. Some ship operators have started using dual fuel engines that are capable of burning LNG for propulsion. LNG engines are considered more fuel efficient with a lower emission factor than conventional bunker fuel (Schinas and Butler 2016). LNG fuel has the additional benefit of virtually zero SO_x emissions and lower emissions for PM and NO_x. There are however concerns on methane slip which is a far more potent GHG than CO_2. For ports, ships sailing using LNG in their proximity will result in improved air quality.

On yard operations, the main environmental benefits will come from the deployment of more efficient ship to shore cranes that will increase the number of moves per hour and thus reduce the total turnaround time of large polluting vessels. At the yard, replacing handling equipment running on diesel fuel with hybrid or electric machinery will greatly reduce emissions at the yard. Deployment of AGVs can also greatly improve efficiency of horizontal moves at the yard while also reduce the requirement for lighting during night-time operations. On the hinterland side, ITS can be used to reduce the formation of queues at the gates. In addition, the gradual renewal of truck fleet coupled with attempts to reduce idling times of drivers will also result in great reductions in emissions at the gate. Finally, in the future the introduction of autonomous freight vehicles and the practices of platooning can also improve the transportation system and increase the capacity of road links near the port.

4.3 Port Initiatives

A number of port authorities are publishing annual reports on their environmental efficiency. The Port of Felixstowe (2017) published its ninth annual environment report for 2016–2017 focusing on energy consumption of in-port equipment and operations. The Port of Los Angeles produces comprehensive annual emissions inventories which have been used in the literature to provide base emission factors per engine type and activity. The inventory includes ship activities which are shown to be the most contributing in SO_x, NO_x, CO_2, and PM emissions.

A number of port authorities have their own green agendas that seek to improve the air quality near the port. Ports are emphasizing different environmental challenges according to their priorities, and therefore, there are initiatives that target all port operations (maritime, yard, and hinterland). An indicative list of programmes that address port operations (maritime, in-port, gate) are presented in Table 12.2.

4.3.1 Vessel-Oriented Programmes

Many port authorities that are not bound by existing regulation have been rewarding vessel operators that follow green practices. For example, in Singapore reduced port fees are required for ships that are using low-sulfur fuel or have good scores in their EEDI. Other ports promote the use of technologies such as cold ironing and offer it at competitive prices as electricity prices are typically lower than low-sulfur bunker fuel. Prior to the SECAs, the Port of Gothenburg would reduce the port tariff for vessels using scrubber systems. An interesting example is the port of Stockholm which provides financial help for retrofitting ferries to use scrubbers, provided their operators commit to call at the port for at least 3 years. Some port authorities are considering investing to LNG bunkering facilities which will result in cleaner vessels calling at these ports. LNG-fuelled vessels pay lower tariffs in Singapore and Rotterdam, while there are plans of the European Commission to develop LNG bunkering services in all EU ports within the Trans European Core Network by 2020 (European Commission 2013). A very successful initiative has been the introduction of the Green Flag Programme (which is a VSRP) in POLA and POLB. These port authorities offer monetary incentives for vessels that reduce their sailing speed in the proximity of the port at 12 knots. Zis et al. (2014) were the first to examine the efficiency of the VSRP programme. They find that it results in significant local emissions reduction at important costs for ship operators (loss of time or speeding up outside the zone). They conclude that the programme could be optimized to be tailored to specific vessel types. Linder (2018) conducted a survey to understand why the VSRP has seen such popularity in recent years, despite the economic penalties associated with its operation.

4.3.2 Non-vessel Programmes and Investments

A number of port authorities are upgrading their cargo handling equipment with the introduction of faster and more efficient machinery. This has positive effects in the energy efficiency of the terminal and at the same time reduces the turnaround time of vessels at berth and thus the vessel emissions generated near the port. Investments in energy generation within the port have been considered in smaller ports where space is available (Shoreham) for the introduction of renewable energy sources.

Relieving bottlenecks caused at the port's gate through improved planning may also contribute to the turnaround time (Zhao and Goodchild 2010). Giuliano and O'Brien (2007) were among the first to examine the effectiveness of the POLA and POLB terminal gate appointment systems and concluded that there was no evidence that the system reduced queues and thus emissions, though lack of ex ante data could have played a role. Truck emissions at the terminal however can be reduced by an

Table 12.2 Examples of green programmes in port authorities around the world

Port	Port operations						
	Maritime					Yard	Gate
	Low-sulfur fuel or scrubbers	Speed	Berth	Ship design/operational aspects	LNG bunkering	Electrification, hinterland operations	
Singapore	Green Port Programme			Green Ship Programme, Green Technology Programme	Available		
POLA POLB		VSRP	AMP	Smoke Stack Reductions (maintenance, control, and alternative fuel)			Clean Truck Programme Green Port Gateway
Gothenburg	Reduced tariffs				Planned for 2015		
Stockholm			AMP and incentive for retrofits				
Antwerp			AMP	Rewards for clean vessels	Available		
Rotterdam				Reduced fees LNG vessels	Available	Investing in RES	
Port of Virginia						Invest in hybrid container shuttle carriers	
Port of Georgia						Yard crane electrifica-tion	

optimized truck arrival pattern (Chen et al. 2013), and additionally booking systems have been introduced. Port authorities also design schemes where trucks below certain efficiency standards are banned from the port (Clean Truck Programme in POLA) and the use of cleaner trucks is rewarded. To reduce hinterland emissions, port authorities could adapt some measures such as:

- Promoting the retirement of older vehicles
- Introducing penalties for delayed arrivals
- Educating campaigns on driving behavior (e.g., reducing engine idling times when waiting)

These simple methods can improve terminal efficiency and the port's environmental performance.

5 Conclusions and Topics for Further Research

This chapter presented an overview of the current status quo on port environmental management. The academic literature is relatively scarce in comparison with research on whole journey aspects, but in recent years, the field of green ports has seen a renewed interest. The chapter aimed to define a green port, as a port that has launched specific initiatives to improve its environmental performance. The environmental challenges that ports are facing nowadays were presented. The role of regulatory bodies in reducing emissions globally was analysed, and examples of how a regulation that is targeting a different area can improve the environmental performance of a port were given. With regard to emissions and energy consumption, the chapter analyzed the different port operations (maritime, yard, hinterland) and the operational practices and technologies that can assist in overcoming these challenges. In emission terms, the most important contributor is the vessel operations, with an important role for specific pollutant types attributed to hinterland road and rail operations.

The author is convinced that the field of green ports will see additional attention in academia and the industry in the coming years, particularly with the potential inclusion of the maritime sector in an emissions trading scheme (ETS). Technologies like scrubbers or LNG engines have seen increased attention following the lower sulfur limit, and interesting research questions will arise from the global sulfur cap from 2020 onward. Cold ironing has already seen an increased attention in academia, and a potential increase in fuel prices may prompt additional vessel operators to consider this option. Research-wise, the main questions revolve around the emerging environmental and economic trade-offs from emissions reduction actions. Considering that ports have limited resources, and the infamous quote that "when you have seen one port, you have seen one port," the main question is how to get the best value for money for environmental programmes. The answer will vary from port to port depending on the throughput handled, the visiting fleet, the position of the port, and many other parameters.

Psaraftis (2016) proposed the push down-pop up paradox, whereby an effort to reduce emissions in one area can result in additional emissions somewhere else. With regard to ports specifically, Zis (2015) proposed the action-reaction concept where an emissions reduction action in one port can lead to increased emissions globally or at other ports. There are many open questions on the arising economic and environmental trade-offs of port emissions reduction options that will require an answer in light of new regulatory pressure that is coming.

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