Fostering energy transition and transport fluidity in European port cities

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Abstract

Europe as a whole is often regarded as a frontrunner in the domain of port-city sustainability, thanks to a wide set of international, national, and local initiatives. This chapter is a review of local initiatives that are either individual (single port city) or collective (partnerships among several port cities), in the domains of energy transition and transport fluidity. We find that individual initiatives concentrate in northern Europe, in the largest ports, and at a few southern ones like Valencia or Marseilles. Conversely, collective actions are more concentrated in the south, including mostly small and medium-sized port cities, through projects financed by the European Commission. Besides, we show that port-urban congestion and PM2.5 pollution concentrate in the demographically and logistically largest port cities, which also dominate container throughput rankings and have the highest number of initiatives. We discuss the imperatives of ensuring a better regional balance across the continent and its port-city hierarchy.

Keywords: congestion; energy transition; Europe; population exposure; port cities; transport fluidity

Introduction

Globally, Europe is recognized as a fertile ground for actions promoting port city sustainability (Puig et al., 2015, 2020). As Gonzalez-Aregall et al. (2018) observe, in their work on the hinterland dimension of green port strategies: "*the region with the largest number of cases with goals to improve the environmental performance of their hinterlands is Europe (…) The reason for this is likely related to the regulatory context of the EU* [European Union]." Another global review, on emission reduction and energy efficiency improvement in ports, concluded that European ports "*continue to be frontrunners in measures implementation*" and, together with North American and Asian ports, prevail in the literature (Alamoush et al., 2020). As Iris and Lam (2019) emphasize, most of the small number of world ports that are certified as meeting the international standard for energy management (ISO 50001) are European; furthermore, the proportion of European ports that have energy efficiency programs increased from 57% to 75% between 2014 and 2016.

This chapter provides a much-needed panoramic view of existing initiatives, should they be individual or collective, due to their dispersion in the academic literature. We find that these measures can be classified as "energy transition" or "transport fluidity", two of the three pillars constituting what can be the model of the "healthy, efficient and sustainable port city" (Figure 1). Integrated (territorial) planning better relates to wider port-city relationships at the interface, and will not be treated in our chapter. As ports are essential bridges between offshore and onshore, their actions may have wider impacts than on the port area or even the port city itself. Energy transition measures are directly aimed at reducing pollution, such as by shifting to cleaner fuels, using renewable energies, or electrifying vehicles. Transport fluidity measures shall facilitate the flow of goods and people, to limit congestion, thereby reducing pollution.

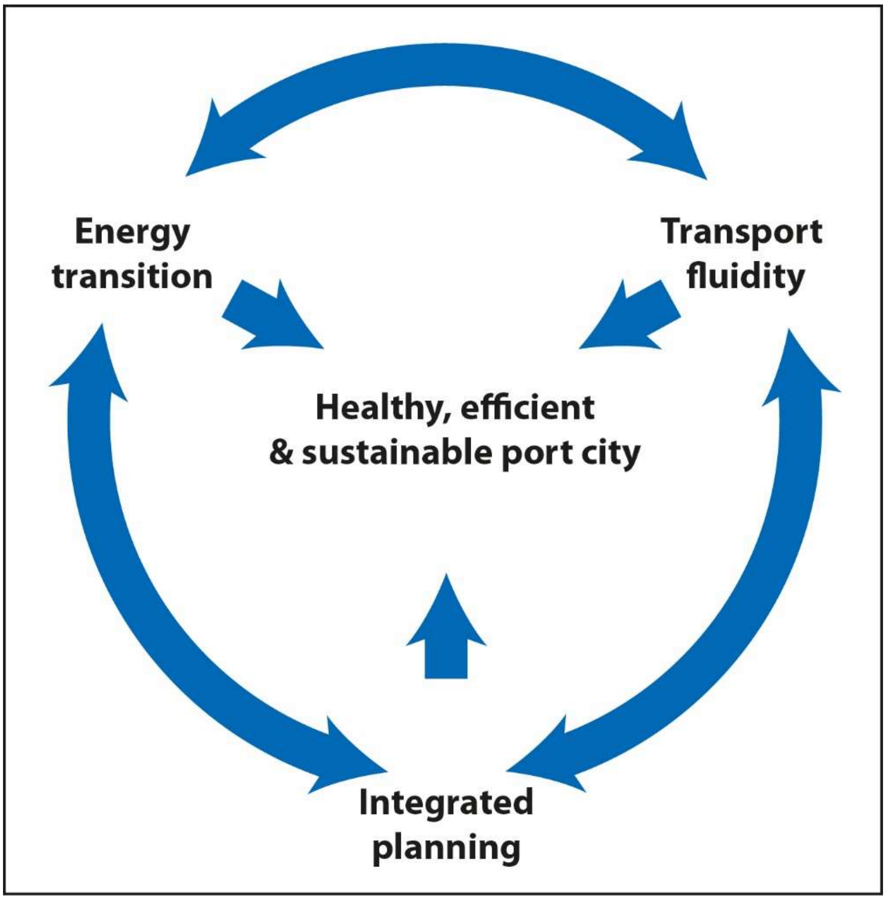

Figure 1: Model of the healthy, efficient and sustainable port city

Source: own elaboration

However, ships operating in the European Economic Area (EEA) generated around 140 million tons of carbon dioxide (CO_2) emissions in 2018, accounting for approximately 18% of global CO_2 emissions from maritime transport that year. Similarly, in 2019, SO_2 emissions in the EEA accounted for 16% of global SO_2 emissions from maritime transport; however, this is expected to fall as a result of stricter legislation (EEA/EMSA, 2021). These greenhouse gas (GHG) emissions not only contribute directly to health harms but also exacerbate climate change, which is linked to several downstream negative health and environmental impacts (Romanello et al., 2021). In the European Union (EU), shipping accounts for 13.5% of all GHG emissions from transport, the third largest contributor following road transport and aviation (EEA/EMSA, 2021). In 2020 the European Commission published its first annual EU report on CO_2 emissions from large merchant ships, which represented 3.7% of total EU CO_2 emissions (EC, 2020). Container ships represented the largest share of emissions, contributing over 30% of total CO_2 emissions. In 2024, total CO_2 emissions from shipping amounted to 140.7 million tons.

Yet, European-wide policies have been put in place to palliate such emissions. Nearly the whole of Europe is covered by Emission Control Areas (ECAs), created by the International Maritime Organisation (IMO) at successive dates (see Figure 2). In addition to IMO regulations, important environmental protection conventions include the OSPAR Convention for the North-East Atlantic region, the Bonn Agreement for the North Sea, the Helsinki Convention for the Baltic Sea, the Barcelona Convention for the Mediterranean Sea, and the Bucharest Convention for the Black Sea. In the EU, relevant laws include the EU Marine Strategy Framework Directive, the Water Framework Directive, the European Green Deal, and the Ambient Air Quality Directive, which provide stringent enforcement obligations to reduce air and water pollution in EU Member States.

The EU-European Trading System (ETS) was extended to the maritime sector in 2024, with the overall objective to reduce GHG emissions by 62% in 2030. Based on an annual threshold, shipping companies declare their emissions, deliver an equivalent number of quotas, and may buy or sell them. This allows to improve the carbon efficiency of ships, push for the use of greener fuels, and optimise routes and speed. The proportion of emissions included in the ETS is due to increase from 40% in 2024 to 70% in 2025 and 100% from 2026. The first carbon bill of 2.9 billion euros was due 30 September 2025, for 13000 large ships, covering 90 million tons of emissions. In addition, the IMO has proposed a ship greenhouse gas (GHG) emission reduction strategy, aiming to reduce emissions by 20%-30% by 2030 compared to 2008, by 70%-80% by 2040, and achieve net-zero emissions by 2050.

The remainder of this chapter is organized as follows. Next section discusses the population exposure to port pollution in Europe. It is followed by another section describing the general trends that characterize individual and collective initiatives. The fourth and fifth sections describe recent and current solutions from offshore to onshore, classified as energy transition or transport fluidity, respectively, based on numerous examples from all over Europe. We conclude about the unequal regional balance of ongoing efforts to make European port cities healthy places to live and work.

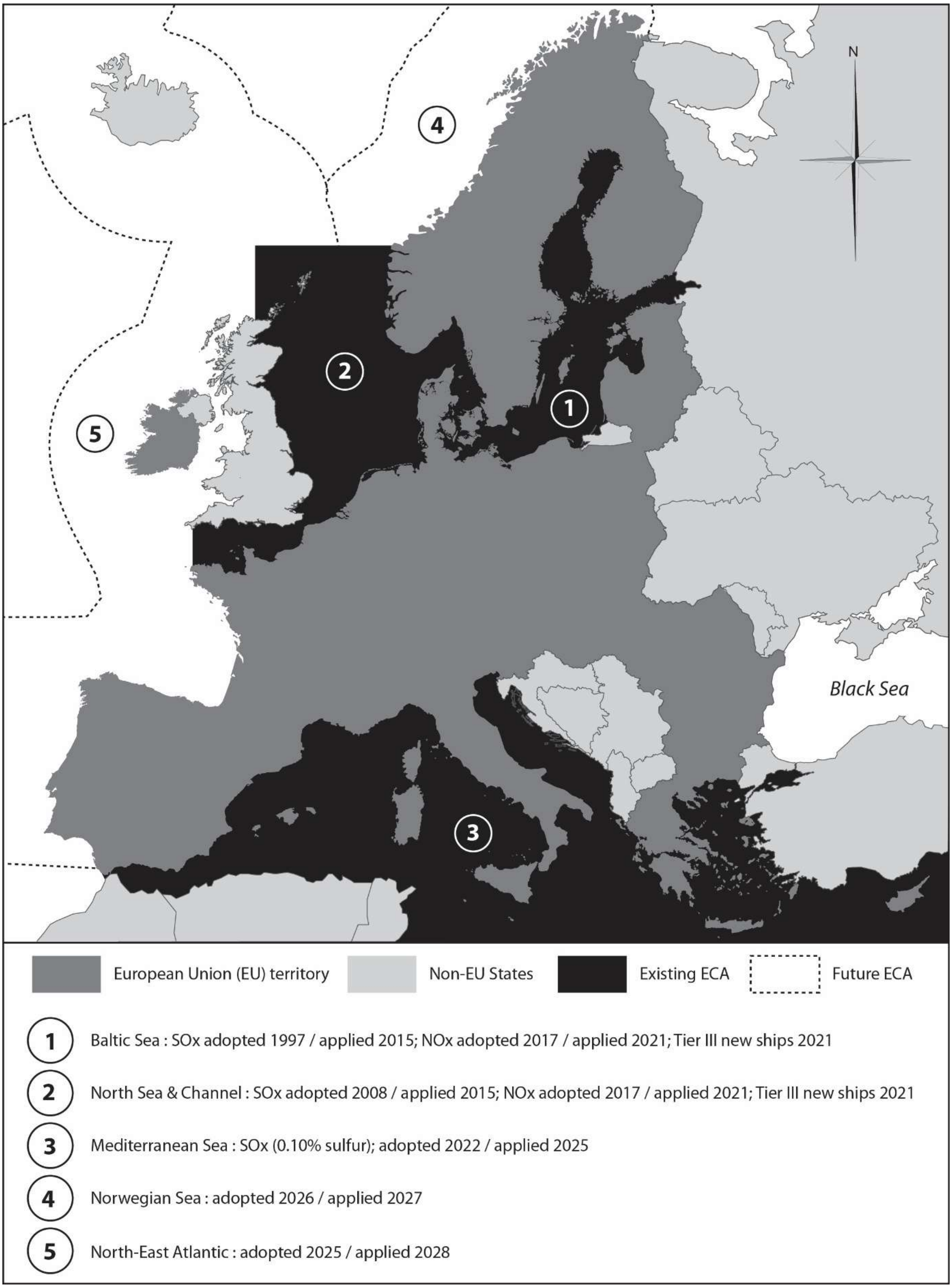

Figure 2: Location map of European Emission Control Areas (ECAs)

Source: own elaboration from various sources

Population exposure to port pollution

This review is motivated by the fact that numerous quays and piers remain active today at the very heart of European port cities, despite the trend of port migration away from urban cores since the 1950s (Ducruet et al., 2023), especially for upstream cities and bulky traffic (see the spatial *Anyport* model of James Bird, 1963). In the long-term, the average distance between port and city in Europe has actually remained very short, compared with world average and other regions: from 3.46 km in 1880 to 3.88 km in 1960 and 4.31 km in 2020 (Ducruet and Polo Martin, 2026). Antwerp and Hamburg, Europe's second and third largest container ports after Rotterdam, managed to maintain port operations upstream, through massive investment in dredging (Notteboom, 2016). Another example is cruise shipping, a source of high pollution, which by essence locates in historic urban neighborhoods to facilitate urban tourism. The study of Barcelona and Valencia by Navarro-Ruiz et al. (2020) showed that the shore excursions of cruise tourists are concentrated in the port cities and cause overcrowding. Several epidemiological studies found evidence about the adverse health effects of ports and related industries, such as in Civitavecchia (Bauleo et al., 2019), Brindisi (Gianicolo et al., 2013), Taranto (Vigotti et al., 2014), but also Athens, Barcelona, Brindisi, Genoa, Melilla, and Venice (Viana et al., 2020). This is often due to prevailing winds carrying pollutions towards populations living near the port, which are often younger and socially deprived (Bertoncello and Hagel, 2016). These evidences confirm that European ports remain very much "urban" (Barberi and Capoani, 2025), implying a superior population exposure to port pollution.

Another way to look at population exposure is to perform a statistical analysis on 70 European port cities using port, transport, pollution, and socio-economic indicators (see Appendix 1.1 for the list of indicators)). Several trends can be observed in this factor analysis, which groups together highly correlated variables (Figure 3). Group A corresponds to a "mass effect" cumulating urban congestion, $PM_{2.5}$ emissions, container traffic, population, and total port throughput on the right (positive) side of the first factor (dim1, horizontal axis). It confirms that container traffic is likely to generate high volumes of trucking, which get mixed with automobile traffic in dense urban areas, especially at peak hours. Taken as a whole, hinterland transport represents twice the emissions of a port on average, for a large container port such as Felixstowe in the United Kingdom (Gibbs et al., 2014), which lacks railway facilities. Other clusters comprise fewer indicators and can be labelled as specialization effects. Group B combines passengers and roll-on/roll-off with CO_2 emissions from ships. This is in line with CO_2 being the largest emission of cruise shipping for instance (90%, the rest being SO_X, NO_X, and PM). Since CO_2 and passengers are projected positively and significantly on dim1, they also participate in the mass effect described above.

Group C is a positive and significant grouping of population, $PM_{2.5}$, dry bulk, and general cargo on dim3 (horizontal). Dry bulk ports, after container ports, are the most likely to contribute to urban pollution through the spread of dust clouds during cargo handling or transport between silo/warehouse/plant/factory and terminal (cement, ores, coal, grain). In the case of Rouen, Europe's largest port for cereals, dust clouds used to spread across the urban area carrying toxic substances like fertilizers and pesticides, before filters were adopted (Morin et al., 2013). Interestingly, the hierarchical clustering analysis revealed a particular cluster of port cities combining high values for containers, throughput, population, $PM_{2.5}$, congestion, CO_2, and passengers. Such a profile, recalling the class of "metropolitan port regions" found by Ducruet et al. (2024), is emblematic of the mass effect described above, and particularly applies to port cities like Rotterdam, Antwerp, Athens (Piraeus), Barcelona, Genoa, Hamburg, London, and Marseilles. Those are both large ports *and* large cities, with a diversified economy and cargo base, concentrating the bulk of maritime freight and passenger flows in Europe. Thus, they are critical nodes in terms of population exposure, fostering the need to launch sustainability initiatives in order to mitigate adverse environment and health effects.

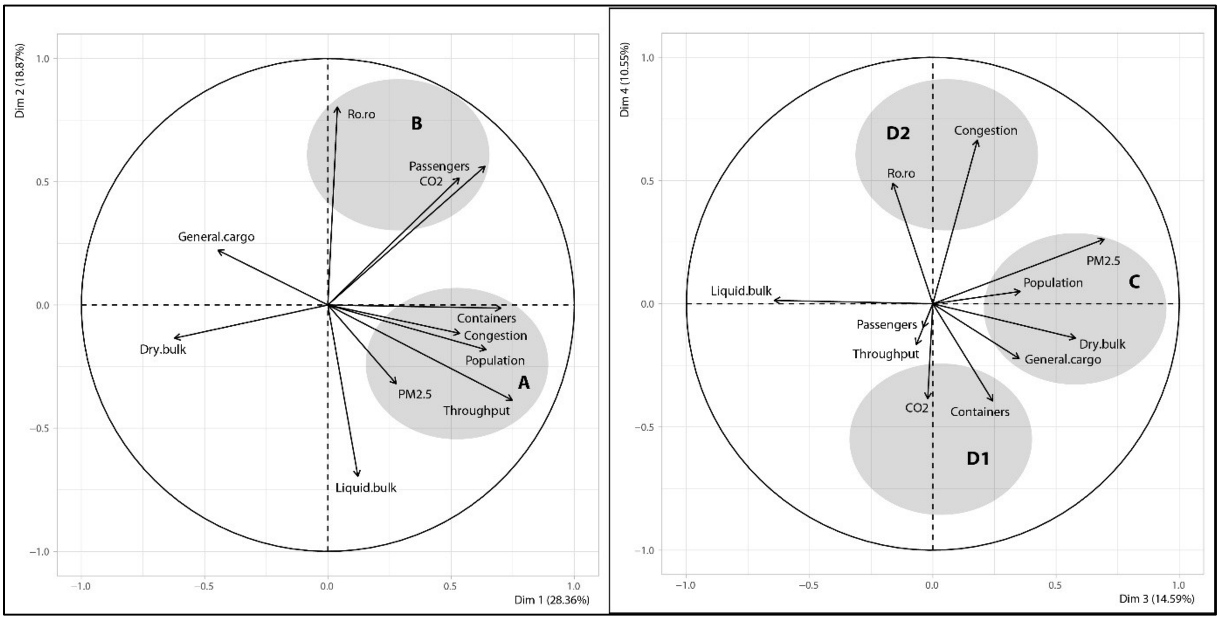

Figure 3: Pollution factors and population exposure in 70 European port cities, 2019

N.B. Ro.ro: roll-on / roll-off (passengers, ferries, self and non-self-propelled vehicles)

Sustainability initiatives at a glance: individual and collective actions

This chapter reports both individual and collective initiatives taken by port-city actors in recent years. Individual initiatives may come from one or more actors in one given port city (e.g., port authority, terminal operator, port industry, municipality, etc.), while collective initiatives involve several port cities within a given sustainability project. Our review is far from being exhaustive. It was conducted during the years 2020-2022 by searching online relevant academic and grey literature, and using specific websites such as the World Port Sustainability Program (https://sustainableworldports.org/). The geographic distribution of individual projects is interesting as it is far from being random (Figure 4). Rotterdam (17 projects), Hamburg (13), Amsterdam (8) and Antwerp (8) take the lead as part of the North European range. They are followed by Gothenburg (4), Felixstowe (4), Dunkirk (4) and Le Havre (3) in North Europe; Marseilles (8), Valencia (4), Barcelona (3), Venice (4), and Koper (4) in South Europe. Thus, there is a strong discrepancy between North and South, East and West in terms of individual actions. As a matter of fact, among the 129 projects scrutinized, 92 locate in the North (71.3%) against only 37 in the South. The next sections will investigate a selection of these projects, classified as energy transition or transport fluidity.

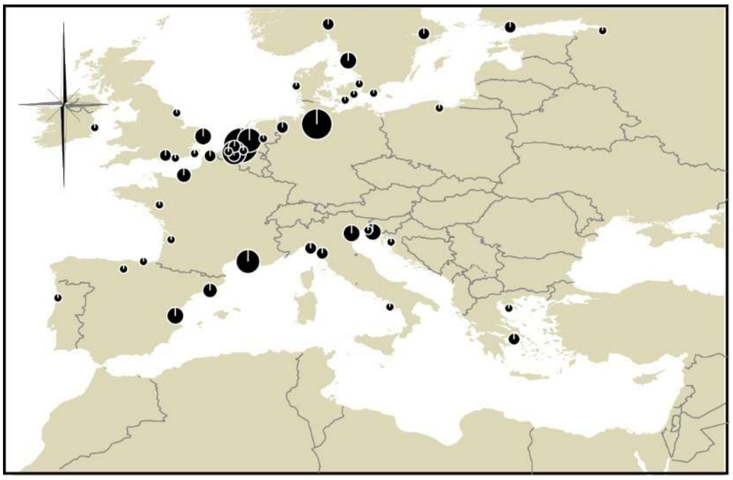

Figure 4: Distribution of individual sustainability projects in European port cities

Source: own elaboration based on various sources

In terms of collective initiatives, a total of 22 projects was found covering the period 2010-2028, reflecting the buoyant activity in favor of sustainability in European ports (Table 1). It also demonstrates the massive support of the European Commission to this topic. Most of these projects were funded by the EC, functioning most of the time with a leader port city, partner port cities, as well as universities, research institutes, and private firms depending on the case. While the size of the projects vary extensively by the number of port cities involved, from a handful to more than 30, their geographic distribution is radically different than that of individual projects. Among the 110 occurrences of port cities, 72 locate in the South (65.5%), against 38 in the North. The most represented port cities are Valencia (9 occurrences) and Trieste (6), followed by Antwerp (5), and Hamburg (4), all of them having a leader role in at least one project. In addition, we observe that many more port cities locate in Eastern Europe (Adriatic Sea, Black Sea, East Mediterranean).

Project	Period	Leading port city	Partner port cities
E-Harbours Electric	2010–2013	Zaanstad	Amsterdam, Antwerp, Malmö
Common Mediterranean strategy and local practical Actions for the mitigation of Port, Industries and Cities Emissions (APICE)	2010–2013	Venice	Barcelona, Genoa, Marseille, Thessaloniki
Green and Effective Operations at Terminals and in Ports (Green EFFORTS)	2012–2014	Bremen	Delft, Hamburg, Rotterdam, Sines, Trelleborg
Green Technologies and Eco-efficient Alternatives for Cranes and Operations at Port Container Terminals (GREENCRANES)	2012–2014	Valencia	Koper, Livorno
Managing the Environmental Sustainability of Ports for a durable development (MESP)	2012–2015	Genoa	Aqaba, La Spezia, Patras, Tripoli (Lebanon)
Smooth Ports	2014–2020	Hamburg	Livorno, Monfalcone, Nantes, Varna
Sustainable Urban Mobility in MED PORT cities (SUMPORT)	2014–2020	Trieste	Durrës, Igoumenitsa, Koper, Kotor, Limassol, Valencia, Thessaloniki
Developing Low carbon Utilities, Abilities and potential of regional entrepreneurial Ports (DUAL Ports)	2015–2021	–	Emden, Hvide Sande, Niedersachsen Ports, Ostend, Skagen, Vordingborg, Zwolle
CIVITAS PORTIS	2016–2020	Antwerp	Aberdeen, Constanța, Klaipėda, Trieste
PORT-Cities: Integrating Sustainability (PORTIS)	2016–2020	Antwerp	33 European Union (EU) port cities
LOOP-Ports project (Circular Economy Network of Ports)	2018–2020	Valencia	32 EU port cities
Sustainable Ports in the Adriatic–Ionian Region (SUPAIR)	2018–2020	Trieste	Thessaloniki
Port IoT for Environmental Leverage (PIXEL)	2018–2021	Valencia	Bordeaux, Gorizia, Monfalcone, Piraeus, Rijeka, Thessaloniki, Trieste
Clean Inland Shipping (CLINSH)	2016–2022	–	Antwerp, North Sea Ports
Towards a Green and Sustainable Ecosystem for the EU Port of the Future (PortForward)	2018–2022	–	Kristiansand, Magdeburger Hafen, Northern Tyrrhenian Sea Port Authority System, Ports de Balears, Vigo
Assessment of Climate Change in Ports of Southwestern Europe (ECCLIPSE)	2019–2022	Valencia	Aveiro, Bordeaux
SUStainable PORTs (SUSPORT)	2020–2022	Trieste	Ancona, Central Adriatic, Chioggia, Dubrovnik, Ploče, Ravenna, Rijeka, Southern Adriatic, Split, Venice, Zadar
Green C Ports	2019–2023	Valencia	Chioggia, Piraeus, Venice
Operational Platform managing a fleet of semi-autonomous drones exploiting GNSS [Global Navigation Satellite System] high Accuracy and Authentication to improve Security & Safety in port areas (PASSport)	2020–2023	Kołobrzeg	Hamburg, Le Havre, Ravenna, Valencia
European flagship action for cold ironing in ports (EALING)	2020-2023	Valencia	Constantza, Varna, Bourgas, Piraeus, Rafina, Ancona, Trieste, Koper, Cork, Barcelona, Huelva, Gijon, Leixoes, Portos do Açores

sMArt Green Ports as Integrated Efficient multimodal hubs (MAGPIE)	2021-2026	–	Rotterdam, Sines, HAROPA
Climate Resilient Port Infrastructure (CLARION)	2024-2028	–	Valencia, Rotterdam, Antwerp-Bruges, Hamburg, Constantza

Table 1: Collective sustainability projects in European port cities, 2010-2028

Source: own elaboration based on various sources

Environmental measures related to energy transition

Abatement technologies

To reduce ship emissions, vessels include exhaust gas cleaning systems (scrubbers) and selective catalytic reduction (SCR) technology (Gonzalez-Aregall et al., 2018). Scrubbers, and more precisely open-loop scrubber filters, allow to reduce PM by 85%, SO_X by 50% and NO_X by 3% (Bjerkan and Seter, 2009). However, using scrubbers for washing at sea may lead to the acidification and pollution of seawater. Such technologies have, still, the advantage to be adapted to conventional motorization systems, and were applied to ships crossing between Marseille and Corsica (the ferries *Piana* and *Girolata*).

Autonomous ships have generally been presented as more cost–effective and environmentally friendly than conventional manned ships (Jovanović et al., 2022). The maritime sector is exploring how alternative powering options could be exploited (cf. wind, solar and battery propulsion), so that hybrid vessels would produce less emissions. For instance, the company La Méridionale was the first in Marseille to electrify its fleet.

Cleaner fuels

Sofiev et al. (2018) projected the global annual health effects of using low-sulfur fuels in 2020, making use of concentration-response functions from previously published time-series and extended follow-up studies. Cleaner marine fuels were predicted to reduce global ship-related premature mortality by 34% and morbidity by 54%. In Europe, around 6400 deaths and 426 000 childhood asthma cases would be avoided annually with the use of cleaner ship fuels. Nevertheless, low-sulfur marine fuels would still contribute approximately 250 000 deaths and 6.4 million cases of childhood asthma annually. Several other studies have also suggested that low-sulfur fuel could reduce premature deaths (e.g. Broome et al., 2015; Viana et al., 2014; Winebrake et al., 2009). One important measure concerning cleaner fuels is the use of green port dues. For instance, the Environmental Ship Index (ESI) is a discount on port dues attributed by the port to shipping companies using cleaner engines and fuels. The index was created by major ports in cooperation with the International Association of Ports and Harbors (IAPH) and has been fully integrated into the IAPH’s governance structure since 2020. ESI is administered by Green Award Foundation, a non-profit organisation that offers a certification and port incentive program for shipping.

In the last decade, the demand for LNG as an alternative and cleaner marine fuel has increased among shipowners. According to Bergqvist and Monios (2019), this alternative not only reduces SO_X emissions by 100%, it also reduces NO_X and PM levels by almost 90%. As underlined by Styhre et al. (2017), using LNG is an attractive option for reducing emissions not only for ships at sea but also for vessels approaching land and for port service vessels. Use of LNG is particularly attractive for ferry and passenger services, which typically occur in close proximity to urban centers (Acciaro et al., 2014). However, recent evidences showed that LNG produces important quantities of methane, a greenhouse gas (GHG).

On the land side, certification schemes and engine standard incentives aim to reduce emissions from trucks entering and leaving the port, while clean vehicles may gradually replace the older fleet based on engine year and fuel type, as in the case of terminal operator HHLA in Hamburg. For the EU, as part of the European Green Deal, the new Euro 7/VII standard promotes further innovation in the design of emissions control systems, such as catalyst and filter technology design, system layout design and system control. By 2030 new large trucks should emit 30% less CO_2 than today, with an intermediate target of 15% by 2025. Truck emissions may also be reduced by using low-sulfur diesel (cheapest), diesel emulsions and biodiesel (Bailey and Solomon, 2004). This is also the case for diesel locomotives, for which a tariff system can impose the use of particle filters and noise brakes (Acciaro et al., 2014).

Inland port dues can be levied based on engine data, with five categories of discounts in the Netherlands. Subsidization is also used to reduce GHG emissions of barge operators in Rotterdam: 25% for research projects, 75% for concrete implementations. The CLINSH (CLean INland SHipping) project is a European consortium promoting clean inland waterway transport (IWT). Dutch, Belgian, German and British public and private organizations work together to improve air quality in urban areas by accelerating IWT emission reductions. The *Argonon*, operated by Dutch company Deen Shipping, is the first IWT vessel in Europe to run on dual fuel, using LNG as its main fuel (80%) and diesel as fuel for ignition (20%).

Cold ironing

This process allows ships at berth to connect shore-side electricity, thereby avoiding to run their auxiliary engines during hoteling activities (cf. power system maintenance, lighting and refrigeration). Electricity can be supplied either by the grid or via renewable sources. EU Directive 2014/94 requires all EU ports to prioritize cold ironing availability (Gonzalez-Aregall et al., 2018). The EU has made it mandatory for Member States to install shore power facilities in ports by 2025. In a cruise port like Copenhagen, which welcomed no less than 30 000 cruise passengers between May and August 2012 (Ballini and Bozzo, 2015), the health benefit of cold ironing technology is considerable, and investments are rapidly profitable.

The technological barriers and requirements include proper voltage, correct connection type, capabilities of power supply companies, grid characteristics, and security (Iris and Lam, 2019). The expense of installation on the terminal and onboard must be considered, as the price of cold ironing use is considerable, but port authorities can incentivize it by subsidizing the electricity price. For example, the Port of Gothenburg currently charges nothing for electricity provision to ferries. The largest capacities of installed power units are currently provided at the ports of Ystad (6.25–10 MW) and Oslo (4.5 MW) for cruise vessels and at Rotterdam (2.8 MW) and Gothenburg (1.25–2.5 MW) for roll-on/roll-off/passenger vessels.

Renewable energies

As noted by Alamoush et al. (2020), 57% of European ports have developed energy efficiency programs, and 20% have adopted measures to utilize renewable energy. Renewable energy installations in the sea for power generation may produce energy from wind turbines on terminal sites or from wind farms (e.g. Rotterdam), from waves (e.g. Mutriku) or from tide differentials (Dover). Onshore wind turbines are also used to cover the energy needs of the ports of Antwerp and Amsterdam.

The use of renewable energies in ports and terminals also includes the installation of solar panels on available flat surfaces, such as port authority buildings or warehouses. In Genoa (Italy), 3600 tons of CO_2 were saved with 29 photovoltaic structures and 100 tons with three solar power stations, while solar thermal installations produce hot water in Hamburg (Acciaro et al., 2014), Rijeka, and Venice. At the Zonneberg park near Ghent (Belgium) and at the Scaldia solar park in Vlissingen and Terneuzen (Netherlands), solar panels generate a total of 110 MW, which is equivalent to the annual consumption of 28 000 households. In April 2020, 1800 solar panels on the roof of the Kloosterboer Delta Terminal at the Maasvlakte (Rotterdam) were put into operation, making it self-sufficient for energy needs. At North Sea Port, green hydrogen is produced from wind and solar power, while Rotterdam hosts the sun-powered freezer warehouse of the cold storage company Frigocare (750 MWh) (Notteboom et al., 2020). With units mounted on the building of a logistics service provider, Amsterdam port (Netherlands) generates 11 GWh of electricity per year, compared with 55 MWh in Gothenburg (Sweden), where units lie on top of the port authority head office. The port of Helsinki (Finland) plans to be carbon-neutral by 2035 by using solar panels on building rooftops and reducing downtown congestion by working actively with the city.

Geothermal energy (dry steam, flash cycle steam, and binary cycle plants) is used for heating and cooling, as in the passenger terminal in Portsmouth. More than 60 geothermal energy shafts were placed under the Värtan terminal in Stockholm, while Marseille hosts the first marine geothermal plant (Thassalia). The latter uses sea geothermal energy to supply heat and cooling to different port buildings connected to its grid, leading to a 70% reduction of associated GHG emissions.

Ports can also use renewable fuels and biomass generation (Alamoush et al., 2020). Biomass production from ports, ships and industries involves using garbage or other renewable sources (corn, living organisms such as algae, wood pellets, etc.) to generate electricity, heat, biogas and biofuels (such as biomethanol, ethanol and biodiesel). Related facilities are found in Rotterdam, Koper (Greenberth project), and Venice (algae). A dedicated biomass rail wagon carrying wood pellets is in operation in the United Kingdom. As part of the DUAL Ports project, the HEAT pilot in the port of Hvide Sande (Denmark) seeks to optimize the production of rest energy from wind, solar and sea-based power systems by integrating it into the local heating system; the carbon footprint is reduced by introducing an intelligent heat pump system combining smart heat exchanger technology.

Industrial ecology

The port can also be a hub for industrial ecology (recycle flows delivery, transformation, re-export) in association with local industries and adjacent residential areas (Cerceau et al., 2014; Spadaro et al., 2021), practicing "green marketing" to attract certified/green clients (Lam and Li, 2019). The principle of industrial ecology in a port context is that companies utilize each other's waste material or by-products, such as heat (de Langen and Sornn-Friese, 2019; Notteboom et al., 2020), or exchange hydrogen. Industrial ecology is more likely to happen when plants are in close proximity, reinforced by a uniform network of local pipelines, such as through the Hidden Connections project (involving Dow, Yara, Gasunie, Volvo and Stora Enso) in North Sea Ports. Clustered companies within the port may develop eco-industrial synergies (CO_2, water and biomass synergies). The Warm CO_2 initiative collects the thermal and CO_2 surplus of the chemical company Yara International to feed agricultural and horticultural greenhouses at Zeeland Seaports; the initiative is promoted by the port authority (Cerceau et al., 2014). In Dunkirk, the DKarbonation project benefits from the support of the central government through the ZIBaC program (low carbon industrial zones), within the framework of France 2030 that is to support energy transition of French industrial areas to make them more competitive while respecting the climate ambitions both national and European.

The products can then be delivered to residential areas, such as heat from the Shell Pernis refinery to the Katendrecht area of Rotterdam, delivered to 50 000 homes through a 26-km pipeline. Based on its campaign "Building a Sustainable Port" and Port Vision 2030, the port of Rotterdam has created a "circularity center", with the aim of reusing CO_2, limiting GHG emissions, and increasing the density of industrial clusters to favor co-firing of biomass in coal-fired plants. The objective of the Smart City project in Rotterdam, in which 60 port companies are participating, is to reduce emissions by 40% through energy diagnosis, awareness, and transfer of energy from port to city. Biopark Terneuzen is another example of the kind, while in Amsterdam, residual heat from the coal-fired plant in the port is transferred to the city to serve 18 000 residents and to make asphalt (Gravagnuolo et al., 2019). The port of Amsterdam has also invested in vapor recovery systems and an emission-laundering system to reduce emissions. It also hosts many recycling companies and has an energy plant where waste is converted into energy; it managed 13.5 tons of biomass in 2020, rising from just 1.65 tons in 2011. In 2018 the engineering company IGES Amsterdam started construction of a plant converting plastic to oil, projecting that it would turn 35 000 tons of polluted plastic into 30 million liters of fuel annually.

The LOOP-Ports project is the first of its kind to bring a circular economy approach to EU ports. Coordinated by Fundación Valenciaport and funded by the European Institute of Innovation and Technology, its aim is to produce a "circular economy network of ports" – to facilitate the transition of the sector, in which products, materials and resources are maintained in the economy for as long as possible and waste is minimized. No less than 44 stakeholders from 14 EU countries are involved in the project: 32 port authorities, four public authorities, three industry associations, four port associations (European Sea Ports Organisation, Baltic Ports Organization, MEDports and Danske Havne) and one environmental organization. The main projected outcome is a complete mapping of EU ports characterized according to their circular activities (the aim is to analyze more than 450 ports and to identify 200 circular activities).

Other projects include the Eco-Partnership and smartPORT energy projects in Hamburg, where the port currently hosts 50% of the city's wind production; the attraction of biofuel producers to the port area in Rotterdam (Alco Energy, Neste, BioPetrol); the development of infrastructures to transport and reuse heat, steam and CO_2, also in Rotterdam (Deltaplan energy infrastructure); the conversion of CO_2 into plastic and CO_2 foam (cardyon) into mattresses and upholstered furniture in Antwerp; and the conversion of CO_2 into bioethanol in North Sea Ports (Steelanol).

In the port of Marseilles (France), the Jupiter 1000 project is the first industrial pilot of Power to Gas, a process in which electrical current is converted into gas through electrolysis of water. Green hydrogen is produced using two electrolysers involving different technologies, exploiting 100% renewable energy. The hydrogen produced will then be fed into the gas network. Alternatively or in parallel, the hydrogen will be used in a reaction with CO_2 captured from a nearby industrial site to produce methane through an innovative methanation technology. The methane can then be injected into the gas network, thereby closing a circular loop as CO_2 will be used to produce energy. WASh2Emden is a project in which Emden port acts as a laboratory for JadeWeserPort and Niedersachsen Ports to study the feasibility of producing green hydrogen and distributing it to the region.

Energy management

One recent concrete example of using a smart grid system is the ESTUAIRE project in Nantes Saint-Nazaire, launched in 2019, which promotes energy storage, photovoltaics and self-consumption. The smart grid is essentially a centralized automated system that manages power flow from the grid to electricity consumers and from consumers back to the grid, utilizing information technology sensors and monitors. Used in Amsterdam port, the smart grid relies on information communication technology infrastructure, with high cost, safety and legal implications, notably in the case of perishable cargo loss or logistics operation crashes due to cyber issues. The microgrid (energy island) and the virtual power plant are subcomponents of the smart grid.

Some measures are associated with the passive house concept, which requires that port authority and other buildings follow ecobuilding standards. A district heating policy has been implemented for high-rise residential and office buildings in Genoa, where the port acted as facilitator for the use of seawater as an energy source (Acciaro et al., 2014). In Koper, the greening of the heating and hot water preparation system helped to reduce losses in the pipelines. In Aalborg, such standards reduced energy requirements for heating by 94%, while in Ghent, advanced insulation and energy recuperation systems were deployed. Self-energy-preserving warehouses have been built in Immingham. In order to prevent heat loss and reduce energy consumption, insulation of windows and walls of port buildings should be improved. Controlling heating, ventilation and air-conditioning through a building energy management system is in place at Dover.

In recent years, the reefer (refrigerated container) trade, which requires continuous refrigeration of each container to keep products cool, has been steadily growing and outperforming other market segments in the liner shipping industry. One way to reduce energy consumption is the practice of shading and spacing, which prevents direct sunlight from heating up containers and their immediate surroundings (by use of sun protection roofs). Reefer container plugs are the biggest energy consumer of port terminals (40% of total consumption), followed by terminal lighting (12%) (van Duin et al., 2019). In addition, gaps between adjacent reefers can be isolated from surrounding air by elastic seals (Alamoush et al., 2020).

In port terminals, dynamic lighting systems meeting real-time operational needs have been deployed both to improve traffic and to reduce energy consumption. In 2017 a full-scale system was installed across the industrial park of the port of Moerdijk; this has 1100 light-emitting diode (LED) streetlights equipped with motion sensors managed by a centralized control system, with different light intensities. Similar systems are also used in Finnish ports and in Felixstowe. Operating costs may be reduced by 80%, and maintenance costs by 50% (Sdoukopoulos et al., 2019). Use of LED lights in buildings, docks, yards, storage areas, warehouses and tugs has saved 70–90% of energy in Venice, and reduced CO_2 by 1000 tons per year in Rotterdam (Alamoush et al., 2020). Another example is the Terminal Dynamic

Illumination at the Noatum Terminal in Valencia, part of the SEA Terminals project, which is expected to make an 80% energy saving. The LED-based system in Emden, part of the DUAL Ports project, extends along a 10-hectare railway reloading point to reduce light pollution. Outdoor lighting is used in the ports of Amsterdam, Barcelona, Bilbao, and Värtahamnen. The rationale underlying the LED projects in Emden, Vordinborg, and Meppel is that different lighting scenarios are preprogrammed in the system, which makes it possible to provide precisely the legally prescribed light quantity for the particular operation (shunting, loading, no operation, etc.). In addition, sensors are used that allow a largely customized switch-on or switch-off of the various lighting scenarios, also reducing visual (light) pollution.

Terminal electrification

Electrification or hybridization constitute a further step towards the reduction of pollution (air and noise as well as water and soil). Electric vehicles may even be powered by wind energy, while their consumption can be reduced by automatic start/shut-off technologies and smart charging systems, as in Copenhagen Malmö Port. Smart load management and load shifting can power cargo-handling equipment outside peak hours to reduce electricity consumption, especially in the case of electrified terminals (Alamoush et al., 2020). Part of this strategy is called peak shaving (load shedding), which involves using intelligent sensors for both buildings and equipment.

Noise and cost reduction is particularly relevant in the case of electrification or hybridization. The electric equipment at APM Terminals in Rotterdam is powered by wind energy, while in Antwerp the terminals run by DP World and PSA International employ hybrid straddle carriers. Recent examples of hybridization can be found in Hamburg, Helsingborg, Livorno, Southampton, and Spanish ports for hybrid-electric rubber-tired gantry cranes. Cold ironing is used in Hamburg to charge battery electric automated guided vehicles (AVGs) and mobility vehicles.

Full terminal electrification was applied in Felixstowe, Hamburg, Koper, Le Havre, Marseille, Oslo, and Piraeus, and through the SEA TERMINALS project in Valencia. As explained by the Green EFFORTS project, "conventional gas- or diesel-powered engines only convert roughly 17 to 21% of the energy stored in fuel to power at the wheels, but fully electric vehicles generally convert roughly 59 to 62% of the electrical energy from the grid to power" (Green EFFORTS, 2014).

Moreover, electrification may extend beyond cargo-handling equipment, to port vehicles in general (as in Barcelona and Koper). Notably, the e-ISLAND project in Santa Cruz de Tenerife and other Canary Island ports launched in 2016 its Sustainable Electric Mobility Plan, which was in line with the United Nations Sustainable Development Goals. The plan comprised installing a network of fast-charging points for electric vehicles for travelers to charge their car batteries while waiting to board their vessels, and acquiring a fleet of zero-emissions port electric vehicles (e.g., surveillance units of the port police and service units of offices and works).

Environmental measures related to transport fluidity

Intermodalism and modal shift

The port city is in itself an intermodal node between sea and land. However, not all port cities use rail or river as an alternative to road, which represents 75% of all intra-EU freight movements (Eurostat, 2019). Modal shift often consists in traffic transfer from road to rail, waterway, or pipelines, potentially alleviating congestion, air pollution, and the risk of accidents. It often necessitates pricing interventions (taxes and incentives), integrated traffic management systems, infrastructure investments, regulation on emission standards, and liberalization of freight markets (Notteboom et al., 2020). Bergqvist and Egels-Zandén (2012) note that a green port due of 2–5% of total cost would be likely to have a significant impact on modal choice decisions.

In green terminal concessions (Notteboom and Lam, 2018), modal split obligations can be used by port authorities to motivate the terminal operator favoring green modes (van den Berg and de Langen, 2014), thereby allowing the port and the terminal to expand their hinterland coverage. Such obligations act as a tool to reduce not only carbon emissions but also congestion, while rail and waterway are more profitable over longer distances. The port of Rotterdam was first to indicate the minimum desired modal split in its proposal request, stating its ambition to shift, between 2015 and 2035, road share from 45% to 35%, rail from 16% to 20%, and inland shipping from 39% to 45%. Yet, once the terminals are in operation, it is difficult to put obligations into effect. Pipelines can replace trucking for the transport of hazardous materials such as liquid bulks as well as CO_2, hydrogen and residual gases, as in the MultiCore pipeline bundle, a joint venture between the storage company Vopak and the Port of Rotterdam Authority. At North Sea Ports, the Clean Underground Sustainable Transport (CUST) study analyzed the feasibility of a pipeline infrastructure in the port area to transport CO_2 and to distribute hydrogen or residual gases.

A green commuting program can encourage port employees and tenants to use carpooling, van pooling, public transport and cycling, providing bicycle storage and parking space to reduce car dependency (Alamoush et al., 2020), as in the CIVITAS PORTIS project (Antwerp, Aberdeen, Constanta, Klaipeda, Trieste). Water taxis are another type of modal shift for passenger transport in the port city, both for on-demand transport and for commuting.

Another solution is rail shipping. The United Kingdom retailer TESCO has implemented a road-to-rail modal shift by linking rail infrastructure to its National Distribution Centre in Daventry. In Amsterdam, the Intermodal Planner digital platform used to provide customers with information on intermodal line connections via short sea, inland navigation, rail and road, while the Green Barge/FloraHolland project is dedicated to transporting horticultural products. Such solutions are more efficient when an on-terminal railyard is available, to minimize the travel distance to berths, with electric cranes to load and unload trains (Sisson, 2006). Hamburg is the largest European port for rail infrastructure; it has 880 switches/sets of points, which are warmed by means of geothermal energy (which is self-regulating and has no emissions). Rotterdam connects the German border with the 160 km-long Betuwe Rail Line.

Barge or rail shuttle systems, replacing trucks, serve to exchange containers between terminals within the port (Gonzalez-Aregall et al., 2018). Barges can be used as floating terminals for bigger cargo ships that cannot enter certain ports, to redistribute containers and replace all transportation by trucks, as seen in Hamburg. PortShuttle in Rotterdam serves to exchange containers between terminals through rail connections. The Intercity Barge focuses on bundling cargo between the ECT terminals on Maasvlakte and other terminals and depots in the Waal–Eemhaven area, Merwehaven, Botlek, Alblasserdam and Ridderkerk. The Amsterdam Barge Shuttle moves cargo from ships and terminals to other terminals on inland waterways to avoid congestion onshore. The Intelligent Railway Point in Hamburg is a multisensor technology that centrally displays the measured values captured whenever a railway point is switched or crossed. The rail shuttle (RAILPORT) in Gothenburg has reduced transport energy consumption by 70%.

Underground freight transport & urban area bypass

Underground freight transport, which uses electrical (or linear induction) propulsion, has "the economic advantages of unimpeded automated transport over a dedicated infrastructure that is separated from passenger traffic" (Visser, 2018). Also called "port-city underground logistics system (PC-ULS)", it provides port cities with more efficient, more economical sustainable freight transport options by building underground links between ports and logistics hubs, industrial zones, railways, airports, and their internal logistics facilities. Moving freight underground can also dramatically reduce negative externalities of port logistics activities, such as environmental pollution (Hai et al., 2020), traffic congestion (Rezaeifar et al., 2022), urban safety (Kumar & Verma, 2022), and scarcity of urban land resources (Chen et al., 2017).

For both road and rail transport, one strategy is to bypass urban areas, to avoid mixing passenger car traffic and freight traffic. Creating tunnels or secondary arteries is one solution, as in the Iron Rhine and Liefkenshoek Tunnel in Antwerp, the Vuosaari terminal in Helsinki, and the new motorway at Salerno Porta Ovest. Other approaches include constructing a new entrance for heavy goods vehicles to relieve traffic congestion near the old town center, as in Koper; installing a buffer zone and traffic control office to prevent congestion by trucks, as at Gapsalskiye Gates in Saint Petersburg; or dedicating a specific route for freight, as in the Betuweroute electric rail line in Rotterdam, and the 3-km track for port traffic only in Leixões. A study of the Dublin Port Tunnel in Ireland showed that road emissions fell between 2006 and 2013 thanks to the new infrastructure, as did traffic in the city center (Tang et al., 2017).

Vessel traffic optimization

Excessive ship turnaround time can be lowered to reduce fuel consumption, but this depends on good coordination of offshore and terminal operations. Several tools can be used in this way. In Finnish, Dutch and Danish ports the use of automated mooring systems (AMS) can help to further minimize turnaround time. As reported by Alamoush et al. (2020), the use of AMS in roll-on/roll-off/passenger terminals can reduce mooring CO_2 emissions by 97%.

Vessel speed reduction (VSR) near the coast helps to reduce fuel consumption and associated emissions, similar to slow steaming. The latter process involves a vessel deliberately reducing its speed at sea to cut down fuel consumption and hence carbon emissions. This can yield an average 12–20% saving in fuel consumption, rising as high as 27% (Alamoush et al., 2020). Other techniques include environmental-friendly hull cleaning and propeller polishing.

Virtual arrival (VA) is a process that involves a vessel coordinating with port authorities to reduce its speed at sea and thus change its arrival time if there is a known delay at the destination port. The reduction in speed results in lower fuel consumption, like for slow steaming, thereby reducing GHG and other exhaust gas emissions. A parent technique is just-in-time arrival, which requires a ship to maintain the optimal speed at sea so that it arrives at the precise time when a berth is available, reducing GHG emissions. Optimal berth allocation, leading to reduced congestion within the port, depends on good coordination between shipping lines, terminal operators, port services (e.g. pilotage) and port authorities. As noted by Styhre et al. (2017) ports can more easily direct their abatement efforts towards ships employed in liner services that make regular calls at the same ports (e.g., container ships and passenger ships and ferries).

Terminal optimization and automation

Optimizing the terminal surface and vehicle mobility, notably through automation, can reduce energy consumption and CO_2 emissions by approximately 70%, as has been seen at Rotterdam Short Sea Terminal (Geerlings and van Duin, 2011). Such a saving is mainly attributable to the shrinkage of travelled distances across the terminal. However, terminal operations internally largely depend on sea and land operations externally, so improved terminal efficiency depends on coping with shipping delays, queuing and prolonged waiting times due to problems related to berth allocation, quay crane allocation, and yard crane, truck or tractor scheduling (Alamoush et al., 2020). One original idea is the Secure Truck

Parking project initiated by Cruise Gate Hamburg in Germany, which aims to optimize overall parking capacity in the Port of Hamburg by turning the parking area of the Cruise Center Steinwerder terminal into a multiuse facility, making an extra 50 spaces available for trucks on days when there are no cruise ship calls.

The concept of ecodriving involves avoiding frequent and/or unnecessary braking and stopping, retaining a steady speed, and shifting gears at low revolutions per minute (Sdoukopoulos et al., 2019). It was found that educating and training machine operators in Copenhagen and Malmö in ecodriving led to a 10–15% reduction in fuel consumption, lower levels of equipment wear and tear, and a cost saving of €95 000. Automated (or intelligent) transport vehicles not only allow productivity and efficiency gains; they also need less light for navigation and are more silent during contact between machine and container (and between containers) thanks to improved handling precision (Bjerkan and Seter, 2019). They can minimize travel distance and turn off the engine when stationary (Sisson, 2006). In addition, automation is safer, as fewer people are on the terminal, and more secure: truckers cannot access containers directly, and computers control and record all container movements. Other advantages of terminal automation are reduced box damage, predictable performance, and less dependence on weather conditions. About 1% of all container terminals in the world are fully automated, while 2% are semi-automated. Further automation faces social costs and does not necessarily mean better productivity and performance (ITF, 2021).

Intelligent logistics through digitalization is itself a solution to reduce fuel consumption, through remote sensing, big data analytics, blockchain, electronic data interchange, one-stop e-business portal sites, and the Internet of Things, to monitor logistics flows, energy consumption and smart operations (Alamoush et al., 2020). Information systems used in ports have several benefits for the port community, such as streamlined multimodal hinterland transport; real-time visualization of automated door systems to tackle truck congestion; road cargo bundling and empty mileage avoidance through horizontal cooperation among transport companies; and optimal and green trajectories of vessels considering intermodal solutions to reach the destination market.

Examples include electronic data interchange (EDI), 3D printing technology used in Hamburg, IoT sensors in Rotterdam to support maintenance and repair, and blockchains used in Antwerp. In Marseilles, the MeRS (Méditerranée Rhône–Saône) project uses blockchain technology to streamline multimodal transport from Marseille-Fos to the hinterland. In Valencia, IoT is used to visualize data from automatic door systems in real time; this allows congestion to be assessed by calculating the time a truck stays in the port, or the time it takes to reach the Noatum Terminal after entering by the southern access. The port authority and the terminals exchange information on wind speeds in order to stop operations at the terminals when they exceed a threshold that could be dangerous.

Originally developed in Hamburg, the Searoutes application was used in the port of Marseilles to calculate optimal and green routes for vessels, based on automatic identification system (AIS) data and using intermodal solutions to reach their destination. EcoCalculator is a web tool used in Barcelona to calculate CO_2 emissions associated with particular sea and land routes. PIXEL project, deployed in Monfalcone, Bordeaux, Piraeus, and Thessaloniki, is an IoT-based environmental assessment tool that measures improvement in selected port performance indicators (e.g. 5% in energy consumption, 6% in average cost per passenger, 85% in average waiting time for vessels and trucks). Another example is the Green C Ports project, a partnership involving Valencia, Piraeus, Chioggia, and Venice, which aims to develop a port environmental performance IT platform based on a sensor network. The objectives are to decrease port traffic congestion and reduce CO_2 emissions from trucks (Valencia); to optimize ship-to-shore crane productivity in the case of bad weather conditions (Venice); and to predict air quality and noise levels to notify government institutions when certain emission levels are likely to be exceeded (Valencia, Piraeus).

One way to optimize truck time at terminals is automated data capture at entry and exit gates to reduce gate time (Sisson, 2006); examples include the use of optical character recognition (OCR) gate portals and Vacis X-ray inspection panels for empty containers. Port-related road traffic may be optimized in several ways at different stages of the transport chain. In Hamburg, for instance, a connectivity platform (Port Road Management Centre) serves to optimize freight flows. To reduce congestion on port access roads, extended gate operations may benefit from a truck appointment system (TAS) or vehicle booking system (VBS); trucks use such systems to book slots, as in Southampton and Felixstowe. The latter port also deploys the PARIS transport management system, an executable transport plan that runs automatically and in real time. Other systems include, among many others, TERMPoint in Gothenburg, e.Brama in Gdansk, and TAMS in Antwerp. The role of such systems is also to manage road pricing through additional port dues. Fees can be applied to trucks at peak hours to shift activity to evenings and weekends, as in the case of the Deurganckdock terminal in Antwerp, which has extended (night) opening hours.

Reducing congestion and related truck emissions is also enhanced by avoiding empty mileage (for instance, through the Central Booking Platform in Antwerp) or by bundling road cargo within a company or between companies (i.e. horizontal cooperation). An example of the latter is an MDS (mutual distribution system) group of five shipping and haulage companies operating out of Le Havre, which manage their transport flows by pooling their resources to optimize collection and distribution. Idling restrictions reduce fuel use, diesel emissions and noise; they may be advertised by placement of no-idling signs for trucks and facilitated by automatic idling control devices for locomotives and other vehicles, the cost of which may be recovered by fuel savings (Bailey and Solomon, 2004). In their study of emission inventory systems, Cammin et al. (2020) underline that ports often lack proper equipment to measure port-related truck emissions. An experimental investigation was proposed by Zamboni et al. (2013) to measure heavy-duty vehicle traffic crossing highway exits, urban zones and port areas in Genoa.

Conclusion

By combining quantitative and qualitative information and performing a literature review, this chapter offers an original and fully-fledged analysis of recent environmental challenges in European port cities. The main findings are as follows. First, the principal differentiating factor of European port cities is a mass effect, whereby congestion, pollution, traffic and demographic size form a hierarchy dominated by a few container hubs. Second, although we find a wide variety of sustainability initiatives, they actually concentrate in North Europe at a handful of port gateways, which correspond broadly to the aforementioned metropolitan port cities. These two elements raise questions about the possibility for Europe to ensure urban and logistical balance across the territory, to avoid such concentration levels of traffics and populations. The funding of numerous projects by the EC, which include many peripheral port cities, seems to be one important step in such a direction.

Based on our analysis, this chapter provides two key findings. First, leading ports in terms of individual initiatives are often large ports not only in terms of traffic size but also in terms of financial resources. They often locate in North Europe, where containerization is a paramuont and stable business, together with strong linkages between bulk trade and industries. Second, collectives actions concentrate in South Europe, where ports witness a notable capacity to create synergies and collaborations, allowing them to benefit from financial support from the European Commission. Such ports are often smaller in terms of traffic size and specialize in passenger traffic (ro-ro, ferry, cruise), while many of them locate on islands and remain peripheral. For these ports, regional balance is a vital stake, as argued by the Conference of Peripheral Maritime Regions (CPMR) that brings together 160 Regions in 24 States from the European Union and beyond.

Thus, there are different levels of port activity in Europe, depending not only due to their diversity of traffic and activities but also in terms of financial capabilities. Such findings also appeared during interviews with key stakeholders of the port and maritime industry, should they be public or private. The discourses of actors show various elements. Despite the existence of individual or collective initiatives, there is always an issue with financial resources, but also with management and governance. For instance, port governance fidders greatly between centralized States, like in Italy (Acciarro et al., 2014), and North Europe, where economies are more liberal. Port governance may allow the emergence of healthy, efficient and sustainable port cities depending on planning policies at different scales and in close synergy with the city and the communities living in the concerned territories where port and maritime activities prevail.

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Indicator	Unit	Source
Total port throughput	Metric tons of cargo handled (LN)	Eurostat
Containers	%	
General cargo	%	
Liquid bulk	%	
Roll-on/roll-off	%	
Passengers	Number of people (LN)	
Population	Number of inhabitants of the urban area (LN)	Citypopulation.de
Urban congestion	Ratio (%) between excess driving time and uncongested conditions driving time (based on real-time information devices installed in vehicles)	TomTom.com
CO_2	Metric tons (LN)	EMSA
$PM_{2.5}$	Mean population exposure to air pollution in the urban area	OECD

Appendix 1: List of indicators to characterize European port cities