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**Abstract**

This paper investigates the influence of multiple vessel traffics on air pollution and public health in European port cities. A sample of 120 Functional Urban Areas (FUAs) is analysed over the period 2000-2019, confronting container, cruise, liquid bulk, and solid bulk traffic with environmental (emissions of $CO^2$, PM2.5, $NO^2$), public health (life expectancy, mortality rate), and socio-economic features like population density and GDP per inhabitant. Results from the fixed effects model show that population density is the major cause of all pollutions, followed by GDP and solid bulks, while life expectancy and mortality are mainly influenced by the nature of the local socio-economic environment (population density, age, GDP, bed rates, educational level). This is complemented by a factor analysis and a hierarchical clustering, which reveal the existence of three types of port cities: critical, tourism, and metropolitan. The typology of port cities is further discussed based on ground observation in particular sites.

Keywords: Europe; Functional Urban Area; hinterland; port city; sea transport; specialization; supply chains

## Introduction

Port cities are critical hubs of maritime commerce and logistics, featuring a wide spectrum of port activities such as cargo handling, oil terminals, shipyards, fishing fleets, and marinas, which collectively generate complex environmental pressures (Coomber et al., 2016; Hernández et al., 2024; Polo-Martín, 2024). Unlike other industrial urban zones, ports uniquely influence air, water, and soil quality through diverse emissions and resource consumption, including water, energy, coal, and land use (Alavi-Borazjani et al., 2025; Konstantinova et al., 2024; Li et al., 2019).

Maritime shipping is a major source of coastal air pollution worldwide, emitting significant amounts of sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs) (Ledoux et al., 2018; Athul et al., 2025; Calgaro et al., 2025). Prior to the implementation of International Maritime Organization sulfur emission controls, ship emissions accounted for 4–9% of global SOx emissions, rising to 30–40% of NOx in some coastal regions (Merico et al., 2020; Ramacher et al., 2020; Hernández et al., 2024). In European ports, shipping contributes notably to particulate emissions, with PM2.5 and PM10 shares reaching 45% and 28% respectively (Merico et al., 2021; D'Amico et al., 2024).

The high emission intensity of cruise liners and ferries further exacerbates pollution hotspots near European ports such as Barcelona, Venice, and Southampton, affecting both port workers and adjacent residents (Merico et al., 2021; Wu et al., 2024). Health risks related to shipping-derived air pollution are substantial, with global premature deaths attributable to PM2.5 estimated between 14,500 and 37,500 annually (Kiihamäki et al., 2024). However, these global assessments often obscure localized impacts, where emissions concentrate within port boundaries and surrounding coastal zones (Jahangiri et al., 2018; Park and Gao, 2025). Emission rates peak while ships are docked, highlighting the importance of turnaround times in managing local air quality (Chen et al., 2019; Zhang et al., 2022).

This chapter innovates in two ways. First, it proposes a simultaneous analysis of different traffic types, more in line with how port cities function in the real-world, since most existing studies consider traffics separately. Second, it wishes to discuss not only the vessel activity itself, but also the indirect impact of traffic-related activities, such as hinterland trucking for containers, tourism flows for cruise and passengers, factories and storage for solid bulks, storage and heavy industrial transformation for liquid bulks. Such a systematic analysis remains missing, which would consider the diversity of related supply chains and of local socio-economic environments. Such an approach would prove particularly helpful to better understand ports' environmental and health impacts on port cities, because most of them handle a variety of cargo types simultaneously, so that air pollutions get mixed in the local atmosphere.

Traffic specialization is partly a reflection of port hinterlands (Marti, 1985), as in the typical case of raw material production such as coal and ores. Large port cities often attract finished goods in containers to meet local demand (Ducruet and Itoh, 2016), while their heritage is a magnet for cruise tourism and passenger traffic in general. Port-related pollution is not limited to ship emissions. Inland transport modes such as trucks, rail, and barges contribute significantly, sometimes exceeding direct port emissions (Mueller et al., 2023; Rowangould et al., 2018; Sun et al., 2025). In Europe, 75% of all freight movements occur by road, so that a large majority of ports are served by trucks to carry containers for import-export (and also transshipment). Thus, ports specialized in container traffic are potentially congested and polluted by such heavy-duty vehicles, especially at peak hours, when mixed with automobile traffic. The port of Le Havre, for example, has an over 90% modal split favoring road transport, leading to traffic congestion and increased pollution, while Antwerp uses barges for about 40% of cargo transport yet still faces significant air quality challenges (Eurostat, 2019; Yu et al., 2025).

The cargo type influences pollutant profiles: liquid bulk terminals emit volatile organic compounds (VOCs) during storage and transfer, whereas solid bulk terminals, including grain and coal handling, generate dust containing hazardous substances like fertilizers and pesticides, posing health risks to nearby communities (Yuan et al., 2022; Morin et al., 2013; Sathish & Patterson, 2025). Another example is the emissions from heavy industries in the port area, such as petro-chemical complexes or “Maritime Industrial Development Areas (MIDAs)”. Such activities are often related with specific traffics such as crude oil for refineries, product tanker, chemicals, and liquid gas, notwithstanding pollution coming from factories. Solid bulk traffic comprises very different traffic types, from ores to grain, coal, and cement, but they have in common to produce dust clouds in the absence of filters on silos or coverage along conveyor belts. The growing cruise industry adds further strain to air quality and local health, increasing exposure to harmful emissions among passengers, crew, and residents (Chatzinikolau et al., 2015; Perdiguero and Sanz, 2020; Lloret et al., 2021). Passenger traffic, of which cruise and ferries, creates important influx of visitors in the port city itself, as well as towards the hinterland for tourism, resulting in crowding and congestion along city arteries and highways, thereby increasing local pollution.

The goal of this chapter is thus to confront environment and public health data to a wide range of socio-economic and traffic characteristics, in order to detect the relative impacts of the latter in a simultaneous manner. A sample of 120 European cities, or Functional Urban Areas (FUAs), is chosen to run statistical analyses, with the main objective to provide a typology of port cities and zoom on the most emblematic cases in each category based on the more qualitative literature (case studies). The remainder of this chapter is organized as follows. The next section provides a literature review about the different traffic types and their various contributions to congestion and pollution, both direct and indirect. It is followed by another section presenting the data and methodology used to analyse the impacts over the period 2000-2019. A next section focuses on a selection of port cities as part of the typology obtained in the previous section. The last section discusses the policy relevance of this research and its contribution to the academic literature.

## The impacts of main traffic types and their related supply chains

### *Container shipping and hinterland trucking*

Container ships represent 4% of the world shipping fleet; however, they contribute to 22% of $CO_2$ emissions (Corbett et al., 2009). To mitigate $CO_2$ from shipping by 19%, 36%, and 51%, vessel speed needs to be reduced by 10%, 20%, and 30%, respectively (Chang and Chang, 2013). Following the 2008 economic crisis, slow steaming reduced $CO_2$ emissions from container ships by 11% (Cariou, 2011). Zhang et al. (2021) investigated the influence of shipping on global air pollution. Findings showed that in 2015, $PM_{2.5}$ linked to shipping led to about 94000 premature deaths globally, representing 83% attributed to international shipping and 17% to local shipping. Utilizing container technologies at ports reduces staying times and improves vessels' efficiency, thereby lowering ship-related pollutants (Agarwala et al., 2021).

At the local scale, the handling of containers on terminals for ships, locomotives, trucks, and shuttles for storage used to rely on heavy fuel in the last decades (Bailey and Solomon, 2004), before recent efforts towards terminal electrification and the use of cleaner fuels. Diesel exhaust "is a mixture of particles, vapors and gases [that] contains an estimated total of 450 different compounds, about 40 of which are listed as toxic air contaminants with negative effects on health and the environment" (Bailey and Solomon, 2004). It can cause eye and nose irritation, bronchitis, cough and phlegm, wheezing, deterioration in lung function, and the initiation of allergies and asthma, while being responsible for various cancers and premature deaths.

Moreover, the combination of trucking and automobile flows "results in considerable congestion and increased pollutant emissions" (Kotowska and Kubowicz, 2019), because "transport congestion in port cities results not only from port-related cargo traffic, but also from the fast economic development of such cities". Viana et al. (2020) conducted a health impact assessment of eight European cities (Athens, Barcelona, Brindisi, Genoa, Melilla, Msida, Nicosia, Venice) for the period 2007–2016, with a particular focus on shipping (oil combustion). They found that shipping causes fewer premature deaths than vehicular traffic, though emissions from both remained comparable in magnitude. Taken as a whole, hinterland transport represents twice the emissions of a port on average, as seen with the large container port of Felixstowe in the United Kingdom (Gibbs et al., 2014). At the regional scale, empty container repositioning is a major cause of congestion and pollution in certain regions, such as Southern California, which had been the focus of many researches on truck routing optimization (Englert et al., 2011).

*Cruise, tourism flows and overcrowding*

According to Paoli et al. (2017), the Euro Zone cruise ship market played an important role in the global cruise market in 2013, accounting for about 30% of European passengers. Furthermore, the European industry generated 31.2 million passenger visits on both the Baltic Sea and the Mediterranean, calling at 250 port cities (Paoli et al., 2017). Yet, cruise is among the most energy-intensive types of tourism and generate a high pollution load (Eijgelaar et al., 2010; Brida et al., 2013). Investigation showed that carbon emissions from cruise passengers are more than five times those of luxury hotels and four times those of economy-class flights (Howitt et al., 2010). Cruise ships are significant emitters of nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM10 and ultrafine particulates), and carbon dioxide (CO2) (Perdiguero and Sanz, 2019). Emissions are particularly high during the "hotelling" phase, where ships remain berthed for hours, continuously running auxiliary engines. For instance, in 2018, 345 cruise ships in Copenhagen Port emitted 291 tons of NOx, accounting for 52% of the port's total vessel emissions (Lansø et al., 2023). Similarly, in Barcelona, cruise ship emissions of NOx, PM10, and SO2 significantly increase when berthed (Perdiguero and Sanz, 2019). Older and larger vessels tend to have higher emissions due to less advanced technology and greater power demands.

The pollutants emitted by cruise ships have a significant impact on the air quality of adjacent urban areas. In Copenhagen, cruise emissions led to hourly NO2 peaks at 50m height reaching 1,048 µg/m$^3$, exceeding EU limits by five times, and annual average NO2 concentrations in the port area were 31% higher at ground level and 86% higher at 50m altitude compared to urban background levels (Lansø et al., 2023). In La Paz, Mexico, SO2 peaks reached 15.71 µg/m$^3$, exceeding WHO standards by 39.28%, with pollution concentrated in a 3.6-hectare water area west of the port (Mendoza-Lara et al., 2023). These emissions contribute to respiratory diseases and increased cardiopulmonary mortality (Lloret et al.,2021; Mendoza-Lara et al., 2023). European cruise hotspots, particularly in the Mediterranean, face more significant health risks due to high population density and intensive shipping routes.

The overall carbon footprint of cruise travel is considerable. A typical 7-day cruise in the Baltic Sea emits approximately 590kg $CO_2$ per passenger (Olaniyi et al., 2022). This is compounded by emissions from port-related land transport, such as diesel-powered shuttle buses, which can add 6,852 tons of $CO_2$ annually for short excursions (Olaniyi et al., 2022). Furthermore, the supply chain logistics contribute to emissions; local procurement (within 20km) can reduce $CO_2$ emissions by 80% compared to remote sourcing (Olaniyi et al., 2022).

The phenomenon of "overtourism" manifests as severe congestion in historic city centers (e.g., Venice, Dubrovnik, Lisbon, Barcelona), diminishing the quality of life for residents and eroding the authentic visitor experience (Abeal-Vázquez et al., 2022; Grindlay and Martínez-Hornos, 2019; Trung, 2019). This concentrated, short-burst tourism model strains local resources such as water supply, public transport, and urban space. For instance, in Barcelona, tourist concentration during weekends and peak seasons leads to facility congestion (Martín-Duque et al., 2022). In Barcelona and Valencia, Navarro-Ruiz et al. (2020) showed that the shore excursions of cruise tourists are concentrated in the port cities and cause overcrowding.

*Solid bulk shipping*

The high demand for bulk commodities such as iron ore, grain, and coal has become an important driver of global trade and port services (Van Vianen et al., 2014). According to Hoffmann et al. (2018), in 2018, solid bulk represented about 53.3% of nearly 11 billion tons of global handled cargo. The increase in air particulate matter in ports and surrounding communities is linked to smoke and dust emissions from loading, unloading, and the transportation of bulk materials (Merico et al., 2019; Lin et al., 2019; Santos et al., 2019). PM can decrease visibility, contribute to acid rain, and impact ecosystem diversity; all of this depends on the chemical and physical composition of particles (Bachmann, 2012). In addition, particulate matter emissions can directly affect health. For example, fine particles with an aerodynamic diameter below 10 microns can enter the lungs and even the bloodstream, and can induce severe acute or chronic disease (Cao et al., 2013). Taking into consideration nearby residents' health potential effect (Lam and Yap, 2019; Borriello, 2013; Cerreta and De Toro, 2012; Saraga et al., 2019), the environmental effect of the activities of the port represents a great challenge to the development of ports (Yang et al., 2017). That's why it is crucial to monitor PM concentrations inside and around solid bulk ports, to establish regulation measures to reduce pollution toward a green and sustainable port development (Bermúdez et al., 2019; Bjerkan and Seter, 2019; Woo et al., 2018).

The case of grain is peculiar as it may be mixed with contaminated earth (fertilizers, pesticides used in agriculture, mycotoxins and microflora), which spread through the air in the absence of filters between silos and ship. Conveyor belts carrying coal (between port and power plant) or iron ore, if not closed, cause spillage and fugitive dust emissions at feeding, transfer and discharge points.

The port city of Rouen in Normandy (France) has been identified by medical experts as having an above-average density of respiratory diseases in recent years. While a direct link with port activity has not been established, handling of cereals in the port has been identified as one potential cause. The port of Rouen is an upstream estuary port located within a city region of no less than half a million inhabitants. Its cereals traffic increased by 1.7% between 2018 and 2019, reaching 23.5 million tonnes, making it Europe’s largest port for such traffic. An investigation into the cereals supply chain indicated that remnants of agricultural soil, contaminated with pesticides and fertilizers, are mixed with grains during harvest, transport, storage and ship loading. The reason for this is believed to be a lack of filters in combine harvesters and silos, which are not fitted by farmers or terminal operators for reasons of cost. Soil remnants spread as dust through the air during ship loading and are carried by westerly winds to nearby urban areas.

Atmo Normandie, a local air quality surveillance association, published an atmosphere protection plan in November 2019, which mentioned “management of particulate emissions from grain transport and storage” (Atmo Normandie, 2019). While this report mentions a decrease in $PM_{10}$ emissions from the grain silos in the port thanks to abatement measures, it does not address health issues. This aspect is more fully addressed by Morin et al. (2013): “Ship loading with food grains emits important amounts of particulate matter in the close vicinity of Rouen harbour terminal (…) The question was to identify (…) a potential danger for populations living in the close vicinity of the harbour terminals”.

*Liquid bulk shipping and petro-chemical complexes*

As ports are often magnets for industrial activity, pollution may also come from a variety of sites, such as power plants, shipbuilding plants, iron and steel plants, nonferrous metal plants, paper and paper pulp plants, oil refineries, and chemical and petrochemical plants. The health implications of residing near such activities have been the focus of numerous studies, including a dedicated WHO report (Mudu et al., 2014). However, these studies do not discuss the specific role of port and related transport/logistics activities (Domingo et al., 2020; Marquès et al., 2020; Martuzzi et al., 2014).

Especially during the loading and unloading of tanker ships, VOCs (methane and nonmethane) contribute to GHG emissions. Among them, the heavier components (nonmethane VOCs) contribute to low-level photochemical oxidants, such as ozone, which affect human health, food production and the environment. Ship demolition or modification can emit asbestos, heavy metals, hydrocarbons and ozone-depleting substances. Additional pollutants include oil itself (accidental discharge, loss from deposit tankers and pipeline), oil and rubber (spill from bulk-handling device), oily and toxic sludges (fuel deposits), as well as polychlorinated biphenyls (PCBs), hydrofluorocarbons (HFCs) and hydrocarbons (ship demolition in developing countries) (updated from the pioneering work of Trozzi and Vaccaro, 2000).

A series of case studies was conducted in industrial port cities in Italy in the past decade or so, demonstrating the health effects of ports but also of the associated industrial areas. In Brindisi, during the period 2001–2007, increased risk (measured by unplanned hospital admissions for cardiac, respiratory and cerebrovascular diseases) was observed when the prevailing wind came from the port and the industrial area, although emission levels of $PM_{10}$ and $NO_2$ remained below legal limits and the results were not statistically significant (Gianicolo et al., 2013). In the port city of Civitavecchia, a study of 71 362 individuals between 1996 and 2013 showed that people living in areas with higher concentrations of PM10 or NOX were younger (18–44 years old) and had a lower socioeconomic profile than people living in less polluted areas. Bauleo et al. (2019) found that residing near the harbour was associated with higher mortality from all cancers and neurological diseases. In Taranto, where 321 356 individuals were enrolled in the cohort and personal follow-up covering the period 1998–2008, the results of the study showed that the district closest to the port (and the steelworks) was less affected than one that was further away, where there was a combination of young age, low socioeconomic status, high deprivation index, and highest SO2 mean concentration values due to topography (Vigotti et al., 2014).

Heavy industrial sites are also of key concern as accidents and hazards frequently occur in these locations. At the same time, the risks associated with transport of hazardous materials to and from such sites should not be overlooked. For France, Georgeault (2015) used the ARIA (Analysis, Research and Information on Accidents) database to demonstrate that a large share of all industrial accidents since the 1960s had occurred at seaport-industrial complexes (e.g. Bordeaux, Brest, Calais, Dunkirk, Le Havre, Marseille, Rouen), followed by several large river port cities (e.g. Lille, Lyon, Paris, Strasbourg). Another accidents database (Major Hazard Incident Data Service (MHIDAS)), covering the whole of Europe, was used by Darbra and Casal (2004) to demonstrate that there had been a drastic increase in events in ports between the 1960s and 2002. The cause of 471 accidents included loss of containment (51%), fire (29%), explosion (17%) and gas cloud (3%), while the main activities were transport (57%), loading and unloading (15%), storage (12%), processing (11%) and warehousing (4%). The transport and loading/unloading categories consisted mainly of manoeuvring of ocean-going vessels (65% and 34%, respectively), the principal causes being ship-to-ship or ship-to-land collision.

As port labour involves handling heavy and voluminous cargo, hazardous goods and big machinery, at dangerous heights and at fast pace, there is a high risk of illness and injury, as well as major and fatal accidents. Lecue and Darbra (2019) analysed about 650 accidents that occurred in European ports between 1961 and 2017; these mainly involved release of oil or derivatives (57%) and chemicals (24%). A minority of these accidents caused death (20%) or injuries (30%). The main activity involved was transport (42%) and transfer (32%), and the main types of accident were chemical release (61%), fire (23%), explosion (16%) and gas cloud (3%). However, the actual health impacts of these accidents were not directly measured, while no information on diseases could be obtained (see also Khan et al., 2021).

## Data and methodology

This study investigates the environmental and health impacts of maritime traffic on Functional Urban Areas (FUAs). FUAs are defined using the harmonised OECD-EU framework, which delineates urban cores and commuting zones based on daily mobility patterns (OECD, 2012). FUAs are composed of:

- City core: Defined by urban centres according to the degree of urbanisation, adapted to the closest local administrative units.
- Commuting zone: Includes all local areas where at least 15% of employed residents commute to work in the city.

To integrate ports into the FUA framework, we applied a 20 km buffer around each FUA. This adjustment accounts for cases where port coordinates fall outside the strict

FUA boundaries due to physical expansion, while remaining administratively part of the urban area. All variables were spatially matched to FUAs and ports using R and GIS techniques. The 20 km buffer ensured accurate association of port data with urban areas. Demographic and economic indicators were aggregated at the FUA level, while maritime and environmental data were linked to port locations. Derived indicators, such as proportions and rates, were calculated using standard statistical methods. To ensure comparability across FUAs and to avoid the country bias, Location Quotients (LQ) were calculated. LQ transformations allow the study to capture the functional intensity of different types of maritime traffic relative to broader regional or national pattern.

To quantify shipping-related $CO_2$ emissions within each urban area, a 12-nautical-mile buffer was generated outward from the boundary of each FUA to delineate the near-shore zone in which maritime activities are most likely to be perceived and to exert environmental influence on the city. For emission data, this study draws on the shipping-related $CO_2$ emissions reported in the EDGAR database under the IPCC 1996 categories 1A3d (international navigation) and 1C2 (domestic navigation). These two categories are merged in EDGAR and jointly provide a comprehensive representation of $CO_2$ emissions from maritime fuel combustion. For each year, the gridded emission layer for the Shipping sector was spatially intersected with the 12-nautical-mile buffer of each FUA, and all grid cells falling within the buffer were extracted. Annual statistics were then computed for each FUA, including total emissions, mean emission intensity, maximum value, median value, the number of intersected grids, and the area covered. Together, these indicators characterize not only the overall magnitude of shipping emissions around each city but also their spatial concentration patterns.

In order to better understand the relationships among the numerous demographic, environmental, economic, and maritime variables (Table 1), the study applies Principal Component Analysis (PCA). PCA is used to reduce the dimensionality of the dataset while preserving the maximum possible variance. This technique identifies underlying patterns by transforming the original correlated variables into a smaller set of uncorrelated components. These components summarise the dominant gradients of variation across Functional Urban Areas (FUAs), facilitating interpretation and subsequent analysis. Following PCA, a clustering procedure was performed to group FUAs according to their shared characteristics. Clustering allows FUAs with similar profiles—regarding maritime activity, environmental exposure, demographic structure, and socioeconomic conditions—to be classified into coherent groups. This step helps reveal distinct types of port–city systems, such as high-traffic cruise hubs, industrial cargo-oriented ports, or low-exposure urban areas. These clusters are then used to interpret how different port–city typologies relate to environmental pressures and potential health impacts.

Given the panel structure of the data (multiple FUAs observed over time), two econometric models are proposed. A Fixed Effects (FE) model is preferred, as it controls for unobserved, time-invariant characteristics of each FUA (e.g., geographic location, historical infrastructure). This approach allows for robust estimation of the traffic effect while accounting for latent heterogeneity. A Random Effects (RE) model may be used for comparison, and a Hausman test will be conducted to validate model choice.

| Category | Variable | Unit of Measure | Source |
|---|---|---|---|
| **Demographic** | Proportion of 65 years old | Percentage (%) | Own calculations |
| | Population density | Persons/km² | OECD |
| | Mortality rate | Deaths per capita | NUTS3 |
| | Life expectancy | Years at birth | NUTS3 |
| **Economic** | GDP per capita | Currency per person | OECD |
| | Unemployment rate | Percentage (%) | NUTS2 / OECD |
| | Education level (ISCED ≥ 5) | Percentage (%) | NUTS2 |
| **Environmental** | PM2.5 concentration | µg/m³ (micrograms per cubic meter) | Atmospheric Composition Analysis Group |
| | $NO_2$ concentration | ppm (parts per million) | Atmospheric Composition Analysis Group |
| | Ship $CO_2$ emissions | kt (kiloton) | EDGAR |
| **Maritime** | Total traffic | Gross Registered Tons | Lloyd’s List |
| | Container | Gross Registered Tons | Lloyd’s List |
| | Cruise | Gross Registered Tons | Lloyd’s List |
| | Liquid bulk | Gross Registered Tons | Lloyd’s List |
| | Passenger | Gross Registered Tons | Lloyd’s List |
| | Solid bulk | Gross Registered Tons | Lloyd’s List |
| | Other | Gross Registered Tons | Lloyd’s List |

Table 1: Selected indicators on European port cities

**Main results**

*Panel data regression results (2000-2019)*

As seen in Figure 1, population density is the major cause of all three emissions, in general (PM2.5, NO2) and from ships (CO2), followed by GDP. Such a result means that the nature of the socio-economic environment is far more important than maritime activities to explain local air pollution. Highly concentrated and productive urban environments tend to emit more than others, due to the agglomeration of people and economic activities. In turn, this agglomeration fosters intensive commuter flows, which may lead to congestion and pollution at peak hours. Solid bulks have a minor but positive influence on PM2.5 and NO2. This importance for emissions in general can be explained by the production of dust clouds from coal, ores, and grain during cargo handling, transport and storage.

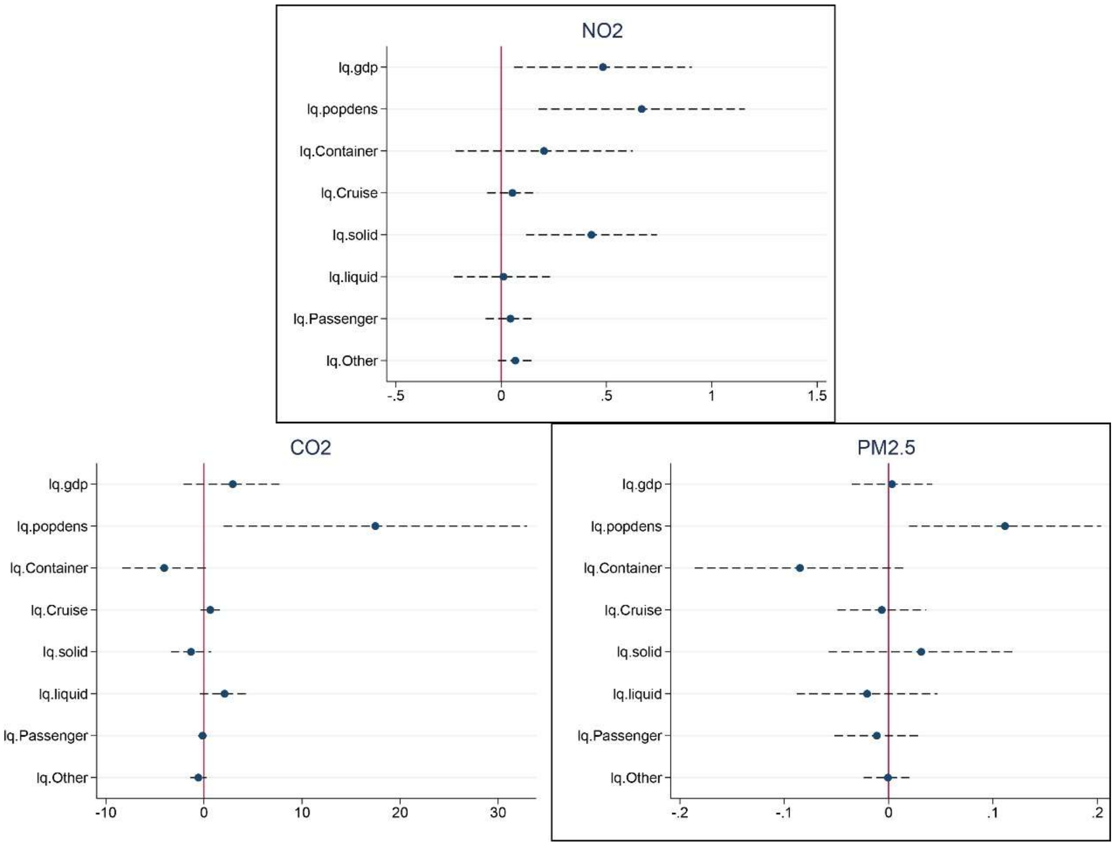


Figure 1: The influence of maritime traffic on local air pollution

The age category over 65 years old has a positive influence on both mortality and life expectancy (Figure 2). This means that ageing cities are more likely to have deaths than other cities, but at the same time, ageing cities witness a longer-than-average lifespan. In terms of traffic, containers slightly increase mortality and strongly reduce life expectancy, while solid bulks increase both, and liquid bulks reduce life expectancy. The high and negative influence of containers and liquid bulks on life expectancy suggests the presence of heavy industries and logistics facilities that create congestion and pollution within port cities. When it comes to the socio-economic environment, GDP, educational level and unemployment reduce mortality, while GDP, population density, and unemployment increase life expectancy. The scores of pollutions are not significant, except for PM2.5, which positively influences life expectancy.

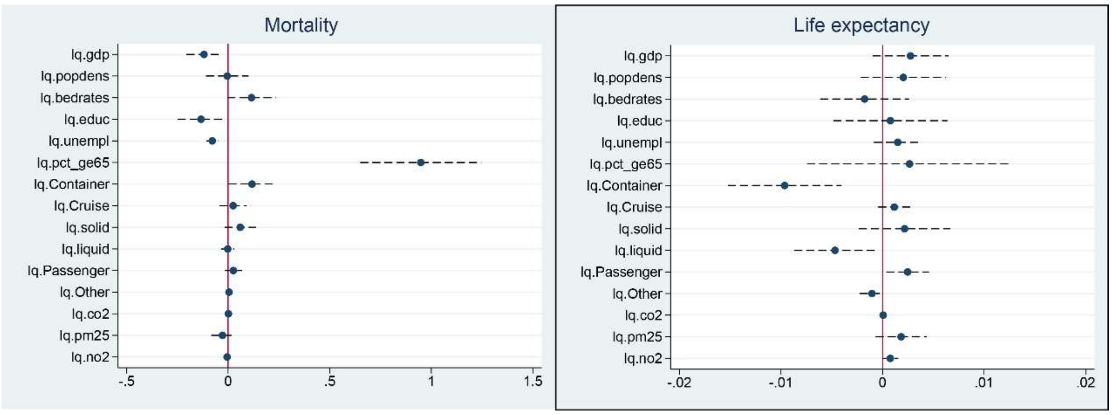


Figure 2: The influence of maritime traffic and pollutions on mortality and life expectancy

*Principal components analysis (PCA) and port-city typology*

Results from the PCA underline several interesting trends about the intermingling of health, environment, and socio-economic dimensions in European port cities (Figure 3). The most negative scores on the second component (vertical axis) include unemployment, cruise, and passengers (including roll-on/roll-off and vehicles).

In the related literature, the relationship between cruise/passenger shipping and employment is ambivalent. On the one hand, several studies confirmed that cruise has direct, indirect, and induced benefits on local employment. Globally, Arlı et al. (2023) found that a 1% change in the number of world cruise tourists reduces the world unemployment rate by 7.6%, suggesting a correlation between cruise activity and employment (see also McWay, 2022; Chen et al., 2019). Positive effects of cruise and passenger shipping on employment were found at the local level in diverse port cities, such as Valletta (McCarthy, 2003), Zadar (Jugović, 2021), and Barcelona (Vayá et al., 2018). On the other hand, Bottasso et al. (2013) found that regional employment in Europe is positively correlated to overall port throughput, but not to the number of passengers. The authors argue that transit passengers do not generate significant local expenditure, and the ferry industry is capital-intensive. Chang et al. (2016) demonstrated that cruise ship visits to the Port of Incheon (South Korea) primarily benefit the Seoul economy in terms of job creation and value added, rather than the local port city itself, which implies a limited direct correlation with local employment in Incheon. This "hinterland effect", which can be found in other places (e.g., Civitavecchia and Rome in Italy), is aggravated by the "seasonal effect", due to the rise of unemployment during the off-season, and its effects on sales, profitability, and investment (Espinet-Rius et al., 2024).

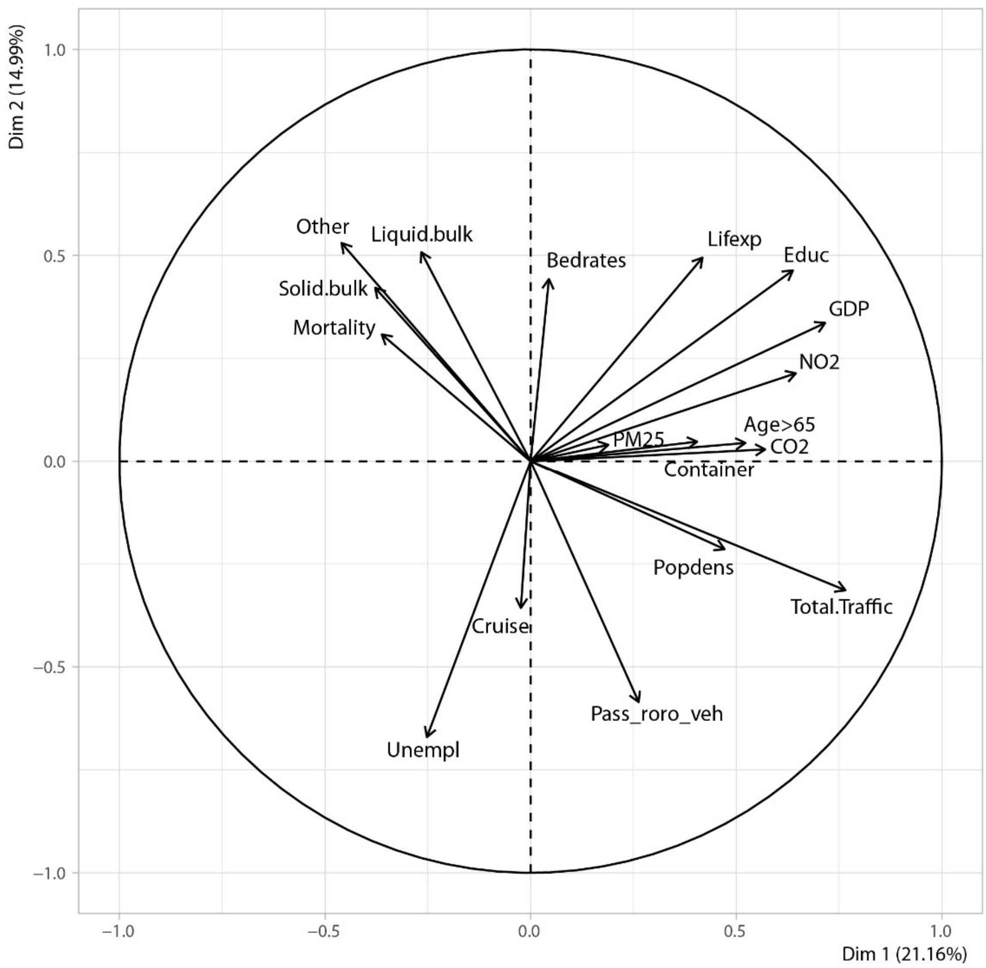


Figure 3: Results of the Principal Components Analysis (PCA)

A second trend is the correlation between solid bulks, liquid bulks, other traffics, and mortality in the upper-left quadrant of Figure 3. As mentioned in our literature review, existing works have already discussed the health risks related with the transport of dangerous goods and hazardous materials. Other works have been conducted, focusing on specific places. For instance, the port of Barcelona is a leading regional distribution hub for hydrocarbons and a vital part of the metropolitan energy production and distribution systems, suggesting a link between bulk cargo (like hydrocarbons/LNG) and urban environments (Nogué-Algueró, 2020). Focusing on the Louisiana Mississippi Chemical Corridor (also known as 'Cancer Alley'), Mah (2015) argues that the production, consumption, and routes of dangerous cargo, including bulk petrochemicals, reproduce a highly uneven geography of toxic risks, burdening the most marginalized and disadvantaged populations. It was also found that in Busan Gamcheon port (South Korea), industrial activities stemming from bulk traffic are responsible for air pollution in adjacent areas because they produce relatively large volumes of particulate matter and oxide dust due to their dusty nature and the processing of heavy cargo (Hwang and Kim, 2020). The authors **e**stablished a causality between scrap metal and fine dust concentrations in the local unit. This can explain why "other traffic", which contains general cargo, participates in the observed trend. Although a PCA cannot account for causal relationships, mortality cannot cause traffic, so that it is possible to confirm that traffic cause mortality, should it be directly (pollution from ships) or indirectly (pollution and hazards from related industries).

The third trend is a large group of variables projected on the right (positive) side of the first component (horizontal). This group is characterized by an intermingling of the three pollutions ($CO_2$, PM2.5, $NO_2$) as well as large total traffic, container traffic, and population density. It is a profile of a large and modern port operating within a dense urban environment, so that port and city combine to create important emissions and congestion. At the same time, such port cities are positively characterized by a higher-than-average educational level, life expectancy, age over 65 years, and GDP. This is a typical profile of a metropolitan area, as in the case of regional and national capitals, which concentrate population and economic wealth, together with a healthy population despite congestion and pollution.

Those three trends actually correspond to three specific types of port cities based on average scores (Table 2) and the cartography of these types (Figure 4).

| | Critical port cities | Metropolitan port cities | Tourism port cities |
|---|---|---|---|
| CO2 | 10.029 | **11.309** | 10.643 |
| Container | 12.049 | **24.696** | 17.493 |
| Liquid bulk | **24.879** | 7.729 | 11.016 |
| Solid bulk | **18.558** | 5.424 | 4.722 |
| Cruise | 6.914 | 10.843 | **12.877** |
| Pass/roro/vehic | 9.836 | 46.687 | **48.190** |
| Other | **27.762** | 4.621 | 5.703 |
| Total traffic | 15.695 | **18.255** | 17.130 |
| PM2.5 | 0.969 | **1.075** | 0.926 |
| NO2 | 0.613 | **1.300** | 0.535 |
| Life expectancy | 0.995 | **1.003** | 0.995 |
| GDP | 0.821 | **1.148** | 0.852 |
| Educational level | 0.882 | **1.072** | 0.901 |
| Unemployment | **1.097** | 0.980 | 1.085 |
| Bed rates | **1.045** | 1.003 | 0.953 |
| Mortality | **1.077** | 0.934 | 1.075 |
| Age > 65 | 0.041 | **0.334** | 0.036 |
| Population density | 0.603 | **1.446** | 0.898 |

Table 2: Three clusters of European port cities

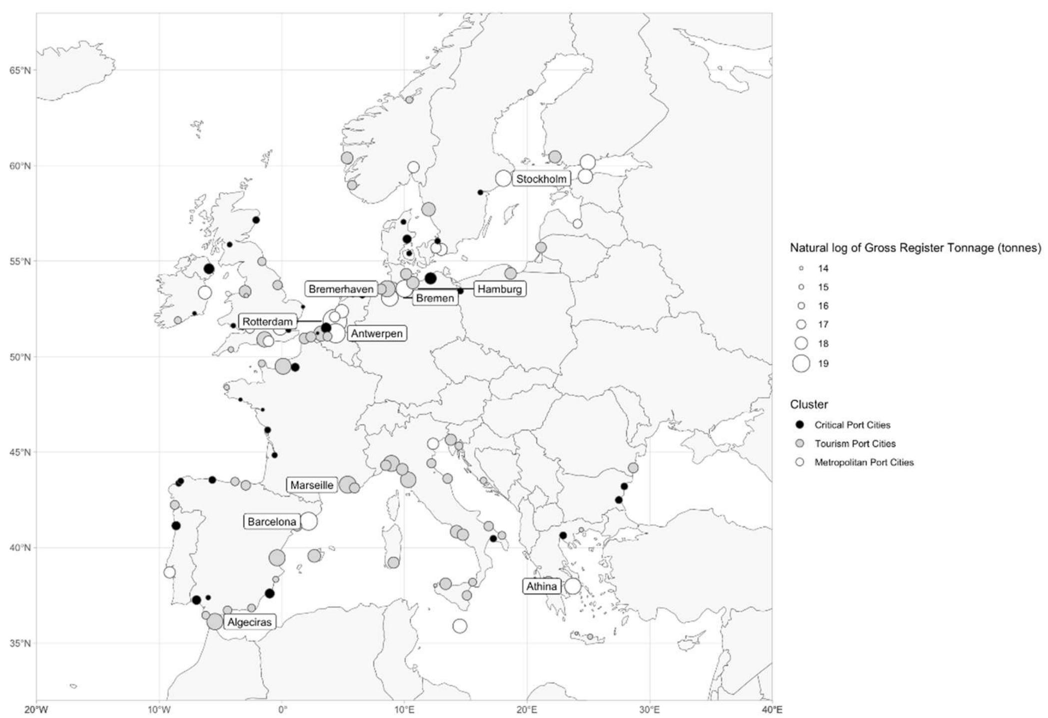


Figure 4: Typology of European port cities

Among Metropolitan Port Cities, we find the main coastal capital cities which ports play a key role in global container shipping. They include Barcelona, Athens (Piraeus), Stockholm, London, Malta (Valletta), Amsterdam, Lisbon, Oslo, Helsinki, Tallinn, and Dublin. These capitals are the principal gateways of their home country. This category also includes regional capitals such as Antwerp, Rotterdam, Hamburg, and Bremen, which are hubs whose activity constitutes a major source of revenue for their belonged country.

Critical Port Cities possess industrial areas which play an important role in the national economy, specializing in liquid and solid bulk shipping. They include Rostock, Belfast, Middelburg, Huelva, La Coruña, Porto, Århus, Thessaloniki, Taranto, La Rochelle, Bordeaux, Lorient, Nantes, and Oostende. They are often small and medium-sized port cities located near important urban centers.

Between those two clusters, a third one is composed of a majority of the sample of port cities, coined Tourism Port Cities due to their important cruise and passenger traffic. Among them, we find numerous insular port cities such as in Sicily and Sardinia in Italy, Balearic Islands in Spain, and certain Greek islands (Chania). A large share of them is located in southern Europe, specialising in ro-ro and cruise, like Tarragona, Marseilles, Genoa, Naples, Brindisi, Split, etc. This cluster is also present in northern Europe, especially for cross-Channel traffic between Calais, mainland port cities, and the British Isles, as well as other port cities in Denmark, Norway (Trondheim), Sweden (Umea), Finland, and eastern Europe (Klaipeda, Rijeka).

Within each cluster, a great variety of actors is in relation. They include shipping lines, multimodal transport operators, terminal operators, port industries, logistics providers, customs services and all other actors which activities compose the “port triptych” (hinterland-port-foreland) (Vigarié, 1979). Whatever the type of flows, the quality and connectivity of the supply chain depend on the capacity of these actors to create synergies allowing the performance of the cluster. This capacity is the vector of competitiveness between ports, which is the engine of port competition, according to traffic specialisation.

Linking traffic specialisation and environmental health impacts is difficult due to lack of data, which hamper more detailed analyses. Despite the limits of this analysis, this research opens the way to question the role of actors in port competition as well as the capacity of territories to absorb environmental health impacts and lower them. If the necessity of a systemic approach is certain, it is confronted to various territorial realities, which differ across maritime regions, countries, and port cities.

## Conclusion

Thanks to this analysis, three key points emerge in order to consider certain limits, and to better understand the territorial dimension of these three types of port cities. First, it is possible to address an “environmental paradox”. In the 1960s, port migration outside urban cores had been motivated by three elements: the lack of space to develop port-related industrial areas, the handling of bigger ships at deep-water sites, and the need for the city to “breath” again while removing negative externalities of shipping and ports. However, this separation has only displaced the problem of pollution, which has intensified through mass traffic to/from these new facilities (Lo Prete, 2023).

Second, there are methodological challenges to measure air pollution from ships. This pollution is mostly invisible, and odorless (e.g. carbon monoxydes), so that human senses are often misleading (Lo Prete, 2023). Another difficulty is to identify the types of pollutants and to verify their link with shipping operations. Certain studies managed to distinguish several pollutants (i.e., SOx, Nox, PM), and the fact that SOx and NOx emissions are particularly high during vessel berthing in the port (Sorte et al., 2019), while PM emissions are more related to cargo handling at berth (Ledoux et al., 2018), especially in the case of solid bulk. Lastly, there is also the difficulty to know which areas are the most affected by pollutions (Lo Prete, 2023). Wind is the principal vector to distribute emissions, and according to wind strength and directions, areas near the port are more or less vulnerable. The invisibility, amplitude and borderless nature of ship emissions amplify the environmental vulnerability of not only port cities but also hinterland cities (INERIS, 2019).

Third, it seems important and necessary to link the port city typology with certain characteristics of maritime basins under study. In the Mediterranean, the three clusters are present, but there is a clear dominance of tourism port cities, for which cruise, passengers and ro-ro have an impact on environmental health. One first challenge is the territorial continuity among Med countries and notably islands (ferries and ro-ro), a condition for port cities to thrive, whatever their size. The second challenge is tourism, as the Med concentrates one fifth of global cruise activity (MEDCRUISE 2024), is the second most popular destination in the world, after the Caribbean (Lo Prete et al., 2024 ; Lo Prete and Kerbiriou, 2025). These traffics (ferry, ro-ro, cruise) thus target both territorial continuity and touristic benefits in the Med.

In the Black Sea, the majority of FUAs are critical port cities, mostly due to the fact that merchant vessels convey a huge share of global bulk traffic in this area, in relation to the industrialisation of those port cities, notably with their strategic role for grain traffic. The Atlantic range possesses all three types of port cities, including a dominance of critical port cities. This relates to the presence of industrial activities in direct relation with maritime traffic, and to national strategies of port specialization to create functional complementarity. In the Channel and North Sea, port cities are very diverse, notwithstanding a strong role of ro-ro and ferry traffic in the Channel to link mainland and British Isles (Lacoste and Lo Prete, 2024). In the North Sea, container traffic dominates, due to dominant hubs along the Northern Range.

To conclude, this diversity and complexity is not carved in stone, as the separation between port cities continues in various places. Port cities face more and more regulatory constraints, questioning their capacity to answer those multilevel rules and challenges. In fact, all new environmental regulations will have an impact on ship operations and, consequently, on operating costs. The cost implications will depend on the mitigation strategies implemented by shipowners and, to a large extent, on how the regulations are enforced in each port city (Lo Prete and Kerbiriou, 2025).

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