Ports and their influence on local air pollution and public health: a global analysis

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Abstract

Despite the skyrocketing growth of environmental studies in recent decades about ports and shipping, the local health impacts of ports remain largely under-researched. This article wishes to tackle this lacuna by assembling untapped data on global shipping flows across nearly 5,000 ports in 32 countries between 2001 and 2018. The different traffic types, from containers to bulks and passengers, are analyzed jointly with data on natural conditions, air pollution, socio-economic features, and public health through multivariate statistics. Main results show that port regions pollute more than non-port regions on average, and this is aggravated by population density and GDP per capita. Three types of port regions are clearly differentiated, of which critical port regions, intermediate port regions, and dynamic port regions.

Keywords: health; maritime transport; pollution; port city; vessel movements

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1. Introduction

The environmental impacts of ports and shipping have attracted a growing attention in recent decades. In 1993 already, the International Association Cities and Ports entitled its fourth international conference "port cities, actors of the environment". In the early 2000s, new research emerged on the integration of environmental values in port policies (Chédot, 2001), in port legislation (Ansaud, 2006), and about the noise of port-related trucking traffic passing through urban areas (Deprez, 2003), to name but a few. Rising environmental concerns often motivated, alongside a wide range of other technical, technological, spatial, and socio-economic considerations, the separation between port and city by the relocation or closure of ports, and the redevelopment of old port areas for new urban uses such as culture and tourism (Hoyle, 1989).

Yet, "*pollution in port-cities, such as measured by* CO_2 *and* $PM_{2.5}$, *is unlikely to be driven only by port activities, but also by other activities of port-cities*" (Merk and Dang, 2013, p. 23). The port is a transport node, but also a magnet for industrial and logistic activities, as illustrated by numerous growth pole and free-zone policies in the 1970s in Western countries and more evidently in Asia. As it will be discussed below, the way urban, industrial, transport, and port pollutions are combined and interact is not well-known. In addition, separating port and city transformed/relocated and amplified/increased rather than erased environmental impacts. Former port cities became served by trucks, while large terminals situated in their periphery created new pressures on outlying settlements, sometimes continuing to affect former port cities albeit at distance, depending on prevailing winds and elevation.

As numerous ports remain urban, research on environmental issues in port cities has been very dynamic in the last two decades (see recent reviews by Carpenter and Lozano, 2020; Wagner, 2019; Zheng et al., 2020). Specific aspects were explored, such as green industrial maritime transport transformation (Comtois and Slack, 2005), industrial ecology (Cerceau et al., 2014), environmental conflicts (Lo Prete, 2012; Bartlomiejski, 2016), urban vulnerability in port cities (Lo Prete, 2015), sustainability of port and port-city plans (Schipper et al., 2017), and stakeholder perspectives on port city sustainable development (Lam and Yap, 2019). This surge of interest goes along with increasing efforts at all levels, from institutions such as the International Maritime Organization (IMO), the International Association of Ports and Harbors (IAPH), and the European Seaports Organization (ESPO), to promote sustainability in ports through a broader environmental vision that also encompasses health issues. Port city actors benefit from ever more advanced methods and precise measurement tools to quantify and map pollutions of all kinds (Azarkamand et al., 2020; Contini and Merico, 2021). For seaport pollution and the correlated health concerns on the local population prevention, the set of technical and organizational solutions available to the port community is very diverse, to improve the fluidity and safety of passenger and goods flows and to lean towards renewable energies and cleaner fuels (Sdoukopoulos et al., 2019; Alamoush et al., 2020).

Nevertheless, two main questions remain largely unanswered: to what extent do ports contribute to local pollution? How much is this contribution detrimental to the health of local populations? The "health" dimension of port impacts/concerns has largely been left aside in the literature. Environmental and health studies are, in fact, drastically different in nearly all aspects (Table 1).

The literature on green ports is so vast that it has been the focus of entire books (Bergqvist and Monios, 2019) and dense review articles (Lam and Notteboom, 2014; Gonzalez-Aregall et al., 2018; Iris and Lam, 2019). In comparison, we have found only four journal articles dealing explicitly with ports, pollution, and health in the entire literature (Gianicolo et al., 2013; Vigotti et al., 2014; Bauleo et al., 2019; Viana et al., 2020). All of them deal with or include a port city in Italy, as these port cities "*represent, at the moment, the most significant social criticality in our country, related to the interplay between environmental assessment and risk for labor*" (Attardi et al., 2012). Although the recent review of the field by Mueller et al. (2023) includes more papers, most of them are in fact health impact assessments looking at health risk factors but without an explicit and direct analysis of actual health effects on the population.

Characteristics	Environmental studies	Health studies
Specialization	Transport studies (operations research, social sciences) and environmental sciences	Medical sciences (e.g. public health epidemiology), interdisciplinary
Methodology	Measurement and mapping of pollutions considered as health risks	Cohort studies; model-based analyses; correlation between population exposure to hazards and health; often cross-sectional or ecological design
Data and monitoring	Pollutions and emissions from different sources, geocoding	Hospital admissions, premature deaths, diseases, socioeconomic status, gender, age, habits
Comparability and timeline	Cross-comparisons, static	Monographs, time series
Decision support	Technical and/or organizational solutions, policy implications	Limited discussion on actors and governance
Health impacts	Health impacts sometimes implicit but mostly not directly discussed	Health impacts explicit

Table 1: Comparison between environmental and health studies in a port city context

Source: own elaboration

More likely are studies about the health impacts of shipping onboard, including the crew and passengers (Mouchtouri et al., 2010; Akamangwa et al., 2016; Lloret et al., 2021). The concept of “environmental health” (OMS Europe, 1994) includes all environmental concerns that can influence *life quality* such as air pollution (interconnection between local population and their environment), and the one of “vulnerability” refers to potential impacts or tangible effects on the local population (Lo Prete, 2015). But, while environmental health focuses mainly on environmental factors that may affect health (e.g., air pollution causing respiratory diseases), the notion of vulnerability also focuses on people who would suffer from the threats or tangible effects of port development as a potential or real effect which would therefore affect public health. This distinction is important to understanding how, today, the health question in a port context cannot be separated from the environmental question and must be considered in an encompassing manner (Allen et al., 2022).

When it comes to health and ports, studies were conducted at the global scale dealing with ship emissions and mortality (Corbett et al., 2007), or impact studies of industrial activities with no specific mention of ports (Martuzzi et al., 2014; Mudu et al., 2014; Domingo et al., 2020; Marquès et al., 2020). The same applies to health studies of port cities that do not mention the port as a factor (on the case of Sydney, Australia, see Broome et al., 2015). Exceptions include analyses of accidents and hazards in ports (Darbra and Casa, 2004; Georgeault, 2015; Lecue and Darbra, 2019).

Our proposed research innovates in several ways. First, it provides an international perspective of the impact of ports on local air pollution and public health across the OECD area. Second, we use untapped data on global merchant vessel movements and a full set of environmental, socio-economic, geographic, and demographic indicators to run multivariate analyses of such impacts at the scale of small regions (of which cities) and large regions. Main results demonstrate whether possessing a port increases pollution, is detrimental to life expectancy, and/or aggravates mortality rates. We differentiate traffic types by their uneven effects on environment and health (e.g., passengers, containers, bulks, etc.) and conclude with a typology of port regions. This typology serves to identify critical cases and as a benchmark to pursue more qualitative research at thinner scales on actual environmental and health protection practices.

The remainders of this article are organized as follows. The second section provides a review of the recent literature on pollution and health impacts in port cities. Thirdly, we introduce the data and methodology. The fourth section displays the main results of the statistical analysis and the cartography of the typology. We conclude in the last section about the lessons learned and propose further research pathways.

2. Literature review on ports, pollution, and health impacts

This section reviews the different sources of environmental and health impacts in a port context, to provide a solid background to data collection and methodology as presented in Section 3.

Most activities taking place in the port city environment are in some way linked to the shipping activity (Coomber,et al., 2016). Yet, some can be found in any city, such as manufacturing, logistics, and heavy industries, while others are specific to ports, such as loading and unloading of goods, oil jetties, shipyards, fishing fleets, marinas, and dredging and building of port infrastructures (Lecue and Darbra, 2019). Various forms of pollution, including air, noise, visual, olfactory and water pollution, can result from such activities, bringing negative consequences for human health and the environment (Sakib et al., 2021).

Table 2 provides an overview of issues and responses related with air pollution from the offshore to the onshore. As such, port and port-related activities not only consume various resources, such as water, electricity, coal and land, but also inevitably damage the urban environment (Li et al., 2019). The vast diversity of threats makes it impossible for the present research to go through each of them in detail. Our choice to focus on air pollution is motivated by the fact that this category contains the largest number of items. This dominance is also reflected in the wide diversity of responses.

Maritime transport noticeably contributes to the degradation of air quality in coastal areas (Ledoux et al., 2018; Mwase et al., 2020; Merico et al., 2020; Gregoris et al., 2021). Air pollutants such as sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs) are emitted to the atmosphere as a direct result of shipping activities (Sorte et al., 2020). In particular, exposure to PM and nitrogen dioxide (NO_2) is particularly harmful to health (EEA, 2019). Annual NOx ship emissions can reach 5-10% of total global emissions, and even 30-40% at the regional level (Ramacher et al., 2020). Before the launch of sulfur limit and emission control areas (SECAs) by the IMO designed under Marpol convention, annual SOx emissions from ships accounted for 4-9% of the total global emissions.

	Offshore			Onshore		
	Ship at sea	**Ship at berth**	**Terminal**	**Port industries**	**City**	**Hinterland**
Issues	Exhaust gases reaching the coast Vessel speed increase emissions Maritime traffic concentration on main sea routes Accidental pollution	Berthing operations (manoeuvring) Exhaust gases when vessel engine runs Vessel queuing (channel entrance) High ship turnaround times	Exhaust gases (diesel-run superstructure) Bulk cargo dust (VOCs, coal, grain, ores) VOCs – evaporation from oil cargoes during ship loading and unloading	Industrial emissions Industrial risks	Exhaust gases (diesel-run heavy-duty vehicles) Congestion, idling Mix of freight traffic and urban commuting	Congestion on main road arteries Empty container repositioning
Responses	Emission Control Areas Spatial technology for maritime surveillance Abatement technologies Cleaner marine fuels Vessel speed reduction (VSR) Autonomous ships Sailing ships	Vapour emission control system (VECS) Cold ironing technology Renewable energies generation Ship turnaround time (TAT) reduction Virtual arrival (VA) Berth allocation	Automation, ecodriving Inter-terminal barge shuttles Equipment electrification Cleaner fuels Modal split obligations Automated door system Absorbing asphalt, smog-eating pavement Shading (reefer plugs)	Industrial ecology, ecologies of scale Virtual power plant Smart grid Passive house Solar panels Environmental monitoring system Filters (bulk terminals) Conveyor belt coverage (coal, ores)	Urban area bypass Underground freight transport Connectivity platform Excess heat and energy exchange Green commuting	Cleaner fuels Modal shift Road cargo bundling Dry port development Truck appointment system Green/inland port dues Fleet retrofit or replacement

Table 2: Overview of air pollution issues and responses from offshore to onshore

Source: own elaboration from various sources

But such global averages must not hide that pollution from ships concentrates near the coast and within ports (Jahangiri et al., 2018). In the latter case, ships pollute more at berth than during maneuvering (Fameli et al., 2020), so that their turnaround time is a crucial factor of pollution, especially concerning NO_X (Sorte et al., 2019), but also PM concentration, which may culminate to 26% in Asian ports (Chen et al., 2019; Zhang et al., 2022). As seen in Table 2, the terminal area itself, port-related industries and logistics also participate to local air pollution, although their contribution is not always clearly measured (Mueller et al.,2023; Rowangould et al., 2020). Merico et al. (2020) and Sorte et al. (2019) quantified the contribution of these emissions to ambient air quality (i.e., ship, terminal, road traffic, refineries), and in the latter study it was found that the combination of trucks, railways, cargo handling equipment and bulk material storage contributed the most to surface PM_{10} concentrations over the study area. A study on the port of Felixstowe (UK) demonstrated that inland transport emissions were double the size of port emissions (Gibbs et al., 2014).

Air pollution in ports also varies according to traffic types. At liquid bulk terminals, the main concern is the emission of volatile organic compounds (VOCs) during the storage and turnover of oil and chemicals (Yuan et al., 2022). Solid bulks (e.g., grain, coal, ores, cement) may produce dust during ship loading and unloading or when carried via uncovered conveyor belts and unfiltered silos. Cereals in particular are mixed with earth residuals contaminated by agricultural fertilizers and pesticides. The study by Morin et al. (2013) on Rouen, Europe's largest port for cereals, was motivated by the fact that "*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 involved in food grain ship loading [and to measure the] particle content of pesticides, mycotoxins and microflora (bacteria, yeasts and fungi)*".

Cruise shipping, which has been a fast-growing sector in the last decade or so, produces emissions that harm the health of not only tourists and residents (Chatzinikolau et al., 2015; Perdiguero and Sanz, 2020), but also crew members (Lloret et al., 2021). When it comes to container vessels, not all port cities use rail or river as an alternative to road, which represents 75% of all intra-EU freight movements (Eurostat, 2019). Ports such as Le Havre in France have a much imbalanced modal split, with more than 90% of hinterland traffic occurring by road. Even in multimodal ports such as Antwerp in Belgium, where barges carry about 40% of hinterland traffic, road congestion may reach extreme levels, due to the combination of transnational and national trucking flows with urban commuting flows, especially at peak hours.

3. Data and methodology for an international study

3.1 Background and rationale

Currently, methodologies on how ship emissions impact air quality and human health are well established and used in cost-benefit analyses of policy proposals (Nazmus et al., 2021). The effect of large-scale air pollution emission changes on ecosystem, human health, and economic impacts can be modelled with reasonable accuracy. However, there is no unified framework to assess the environmental and socioeconomic impacts of ports and shipping (Ytreberg et al., 2021). Existing studies use a wide variety of methods, including experimental observations, numerical modelling, and emission inventory analysis (Merico et al., 2017). Some scholars conducted on-site sampling campaigns and quantitatively evaluated the impact of ship emissions on port air quality based on the measured data (Wang et al., 2019; Peng et al.,2022). Steffens et al. (2017) used the mobile measurement method to assess the air quality of the port, which is more flexible than the fixed monitoring station. Mainstream methods to estimate ship emissions in ports are either top-down (i.e., fuel-based) or bottom-up (i.e., activity-based) (Nunes et al., 2017a; Yang et al., 2021; Toscano et al., 2021). The bottom-up approach for instance was adopted by Sorte et al. (2021) in their detailed emissions inventory covering shipping and cargo handling (see also Kara et al., 2021 for container ports).

However, environmental impact studies focus on ports rather than port cities, and health impacts are only implicit (cf. Table 1). There is a strong difficulty to disentangle the contribution of each source to total local pollution, due to complex interactions among them and rapidly changing meteorological conditions (Lang et al., 2017). To simulate urban-scale pollutant concentrations, Ramacher et al. (2020) used the coupled prognostic meteorological and chemistry transport model (TAPM) to measure the contribution of road traffic and shipping related emissions to total air quality and annual mean population exposure in Hamburg. Merico et al. (2019) proposed a system integrating dispersion modelling and measures issued from both meteorological stations and traffic data inside the harbor. Despite their regular advances, such experiments still have limitations due to the complexity of chemical processes in the atmosphere, the difficulty of source attribution, and limited spatiotemporal data resolution.

Studies with an explicit focus on health impacts are usually done at the intra-urban level. In Civitavecchia, Bauleo et al. (2019) showed that people living in areas with higher concentrations of PM_{10} or NOx were younger and had a lower socioeconomic status than in less polluted areas, while residents near the port had higher mortality from all cancers and neurological diseases. In Brindisi, Gianicolo et al. (2013) found that health risks (i.e., unplanned hospital admissions) increased for people living under prevailing winds carrying PM_{10} and NO_2 and coming from port and industrial areas. In Taranto, the district most affected by the port and steelworks (i.e., young age, low socioeconomic status, high deprivation index, and highest SO_2 mean concentration) located at distance due to topography (Vigotti et al., 2014). According to Viana et al. (2020) in their study of eight Mediterranean cities, shipping caused fewer premature deaths than vehicular traffic, though emissions from both remained comparable in magnitude. More recently, Gillingham and Huang (2021) used vessel tonnage and patient-level administrative data over the period 2001-2016 to demonstrate that air pollution from U.S. ports affects health outcomes but differ by race, as respiratory hospital visits, heart-related visits, and psychiatric visits are three times higher for Black people than for whites.

The level of detail and diversity of measures offered by these studies largely explain the rarity of comparative analyses internationally and even within the same country. This is also due to the relative uniqueness of port sites, urban morphologies, and climatic conditions from one place to the other. Therefore, we present in section 3.2 below the data and methodology capable, for the first time, of running an international and comparative analysis of the environmental and health impacts of ports.

3.2 Main hypotheses for an international study

Based on the above, our main hypotheses are as follows:

> H1a: the presence of a port aggravates air pollution and health conditions
>
> H1b: regions hosting a port witness heavier environmental and health impacts than regions without ports

This can be verified by a statistical analysis, first willing to test whether ports significantly affect pollution and health, although local environmental and health conditions are influenced by other activities and a number of natural and human factors. Given that ports are very diverse across the globe, traffic hierarchy and specialization should also be considered:

> H2: impacts are higher for larger ports than for smaller ports
>
> H3: impacts are differentiated across traffic types

While the quantity of traffic passing through ports should inevitably result in more air pollution, this is less evident when it comes to differentiate traffic types. Unfortunately, there is no data source on the respective importance of trade and transshipment at ports, so that we principally focus on cargo types. Those act as "supply chains" each having its own rationale. As mentioned above, solid bulks like cereals provoke dust clouds in port cities, while container traffic pollutes mainly when carried onshore between the terminal and the hinterland, especially in a dense urban environment for trucks to go through. Thus, air pollution will vary in nature and intensity depending on traffic types. The consideration of traffic types is also important because of their particular regional branching and industrial relatedness (Ducruet and Itoh, 2016). Bulks shall be produced or consumed more locally by heavy industries, compared with containers that feed more distant customers or concentrate in dense urban regions (Guerrero, 2014). Cruise shipping implies long turnaround times for vessels during port stay, as well as important road traffic for tourists (Tichavska and Tovar, 2015).

All these effects, however, should be tested under the umbrella of several control variables. Since our database covers nearly 5,000 ports, it was impossible to characterize them with the attributes presented in Table 2. Further research on a smaller sample and at port level shall determine whether the adoption of environmental-friendly practices helps lowering the impact of ports, such as cold ironing/shore power and modal split obligations. Nevertheless, as earlier research already showed for instance on Chinese (port) cities, wind speed and rain precipitations can lower air pollution through dispersion and dilution (Liu et al., 2017; Zhang et al., 2023). Conversely, topography (elevation) and climatology (influencing soil temperature) are known to aggravate pollution and health impacts (see Zhao et al., 2020).

3.3 Data and methodology

The proposed international perspective uses the port region as the spatial unit of analysis. The OECD territorial database, which covers about 2,000 regions in 36 countries, is the main data source, which provides socio-economic, environmental, and health indicators at two regional levels, namely small regions (TL3) and large regions (TL2). While these regions correspond to subnational administrative units, small regions of the United States are functional economic areas. We combine this database with the one from *Lloyd's List* on global shipping, which main advantage is to palliate the absence of a global database on actual port throughput.

As seen in Table 3, Lloyd's data allows calculating ship traffic at ports in total and by type of ship, which corresponds to the product between ship capacity (gross registered tons) and number of calls on a yearly basis. We excluded non-commercial vessels, like navy ships and hospital ships for instance, but kept those performing port services (i.e., towage, pilotage, dredging) as they contribute noticeably to port pollution. Some traffic categories could be disaggregated, like liquid bulk (i.e., chemicals, crude oil, gas, oil tanker), contrary to containers, general cargo, and solid bulk. Passengers and vehicles include the subcategories ferry, roll-on/roll-off, and vehicles, which are highly correlated when considered separately. Aggregates, cement, ores, and wood were kept within solid bulk due to their small weight, as for fish products and general cargo, for the sake of reducing the number of variables and keeping relevant categories. Traffic was summed for regions containing more than one port. As high ship turnaround time is recognized as a factor of pollution in the literature, it was calculated as an average for the whole fleet by region and by year.

The OECD territorial database provides information on two main pollutions, namely mean population exposure to $PM_{2.5}$ emissions (µg/m^3) and Greenhouse Gases (GHG) emissions (million tons CO_2 equivalent). Unfortunately, air pollution in PM_{10} is only available for 2010, CO_2 emissions for 2008, and NO_2 emissions for 2012, so they were not considered in the present research. Interestingly, GHG emissions are decomposed by origin, of which industries, transport as a whole, and road transport in particular. It allows our analysis to run several, complementary models for distinct impacts. The retained health indicators are life expectancy at birth and mortality rate. The mortality rate is decomposed by cause (respiratory, circulatory, and transport). Among all possible socio-economic variables to retain, a drastic selection has been made: population density and GDP as potential factors of increased pollution, and employment in port-related activities (industry, transport).

Last but not least, the geographic characteristics of cities and regions were collected from the website Copernicus[1], a dataset providing daily surface meteorological data for the period from 1979 to present. Among all possible indicators, we retained the most relevant to study port pollution, namely temperature, wind speed, and precipitations. While temperature is known to increase pollution, wind speed and precipitations reduce it, by their dispersion role. The method has been to calculate the yearly average for each region from individual station data, using QGIS and the shapefiles of regions. Descriptive statistics for the retained indicators are provided in Appendix 1.

[1] https://cds.climate.copernicus.eu/

Category	Variable	Description
Port traffic	Total vessel traffic	Gross tonnage (GRT) (LN)
	Containers, liquid bulks, passengers & vehicles, solid bulks	% in regional total
	Average ship turnaround time	Average number of days spent by vessels in ports
	Port dummy	0/1
	Emission Control Area (ECA)	0/1
Geography	Wind speed	Knots
	Precipitations	0.01 inches
	Temperature	Farenheit
Pollution	Particulate matter ($PM_{2.5}$) emissions	Average level experienced by the population (μm/m^3)
	Total CO_2 equivalent emissions	Metric tons (LN)
	CO_2 equivalent emissions by source (transport, industry)	% in total emissions
Health	Mortality rate	No. deaths per 1,000 people
	Mortality rate by cause (respiratory system, circulatory system, transport)	% in total deaths
	Life expectancy at birth	No. years
Socio-economic	Gross Domestic Product (GDP) per capita	$US per inhabitant (LN)
	Population density	No. inhabitants per km^2 (LN)
	Employment in manufacturing, heavy industries & energy, transport & accommodation	% in regional total

Table 3: List of regional variables

Source: own elaboration from various sources

The core of the analysis will consist of the following and complementary steps. First, a multiple regression on panel data over the period 2001-2018 will estimate whether having a port is detrimental to health and environmental conditions, through a comparison of port and non-port regions. Second, we examine how traffic size and specialization influence health conditions and pollution levels. Third, a factor analysis will be applied to the most recent year (2018) in order to describe the main trends at stake in terms of correlations, before providing a typology of port regions via a hierarchical clustering analysis. This typology will allow us to identify the most critical places and pave the way towards a more qualitative approach. Whenever data is available at both levels, we will run these analyses for both large and small regions to check whether geographic scale matters for the relationship between ports, pollution, and health.

4. Main results

4.1 The effect of having a port

The first analysis focuses on the port dummy to verify its effect on environmental and health conditions. For the main environmental, health, and socio-economic variables, we calculated the ratio between the average score of port regions and the average score of all regions (Figure 1). This allows to answer positively the fundamental question about whether port regions are more polluted than non-port regions, in terms of GHG emissions. This is the case for both large and small regions, but the gap between port and non-port regions is much wider in the case of small regions (1.5-1.6 compared with 1.1-1.2). Although such results cannot account for a direct and causal effect of ports, environmental issues are more critical for smaller territories having a port. This is not the case of the exposure to $PM_{2.5}$ emissions, given that the ratios are lower than 1 for both large and small regions. Small port regions are also characterized by a higher population density and GDP per capita on average, which accentuate GHG emissions and at the same time, the exposure to such emissions. However, health indicators show no specificity, except the mortality rate that is lower than average for small port regions, while life expectancy is more or less the same between port and non-port regions. At this stage, it is only possible to establish links between GHG emissions and the concentration of population and economic activities when a region has a port. The relationship with health conditions needs further investigation using other methodologies.

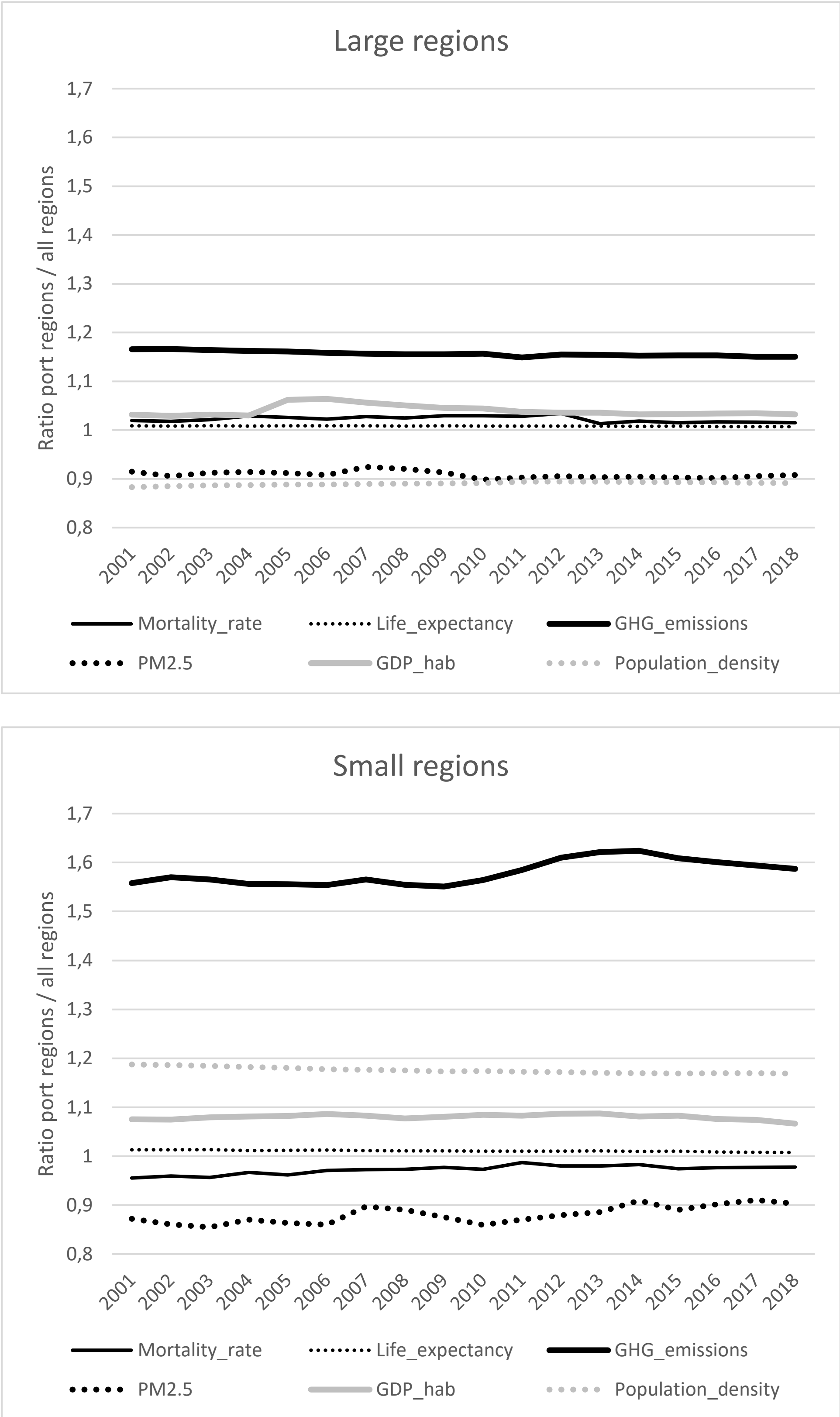

Figure 1: Comparison of port and non-port regions, 2001-2018

Using multiple regressions, the port dummy is significantly positive and has the expected sign for GHG emissions, for both large and small regions (Table 4). However, it is significant and negative for the exposure to $PM_{2.5}$. This is justified by the fact that $PM_{2.5}$ is less directly related with port and port-related activities, which are more conducive to emit greenhouse gases like CO_2, resulting from the burning of fossil fuels by vehicles and industries (coal, oil, and gas). Another reason is that $PM_{2.5}$ emissions in coastal regions, of which port regions, are lower than in non-port, inland regions due to winds. This is well apparent in Table 4 as wind speed is significantly and negatively influencing $PM_{2.5}$ pollution, which mainly consists in smoke and dust. Conversely, higher temperatures foster both pollutions, in accordance with the literature (Zhao et al., 2020).

Secondly, the port dummy is confronted with health indicators (Table 5). For mortality rate, it is significant and positive on large regions only, while for life expectancy it is always positive and significant. What looks like a contradiction could signify that the port effect will differ according to more complex phenomena than just the presence or absence of such an infrastructure. Besides, population density and GVA per capita lower mortality for all regions, while it increases life expectancy, which is a more meaningful result. It is worthy of investigation to include air pollution indicators in the model. If the effects of GHG emissions and $PM_{2.5}$ are contradictory for mortality rate between large and small regions, $PM_{2.5}$ lowers the life expectancy of both small and large regions. Given that $PM_{2.5}$ is lower in port regions (Table 4), this lowering of life expectancy is more likely to apply to inland, non-port regions. However, the unavailability of additional data, such as about medical care (e.g., number of doctors, hospital beds), hampers the models' results. This motivates us to enrich the analysis with more information about ports, which can be differentiated by their traffic size and specialization.

Large regions	GHG emissions					Exposure to PM2.5				
	R	R2	Adjusted R2	S.E		R	R2	Adjusted R2	S.E	
	0.413	0.171	0.170	55.910		0.614	0.376	0.376	5.405	
	Beta	S.E.	Stand. Beta	t-value	Significant	Beta	S.E.	Stand. Beta	t-value	Significant
Const.	-76.333	4.058		-18.812	<.001	24.300	0.392		61.943	<.001
time_trend	-1.217	0.130	-0.103	-9.325	<.001	-0.178	0.013	-0.135	-14.092	<.001
Wind_speed	4.006	0.443	0.104	9.037	<.001	-0.797	0.043	-0.185	-18.602	<.001
Precipitation	0.258	0.094	0.029	2.740	0.006	0.049	0.009	0.050	5.392	<.001
Temperature	2.686	0.117	0.251	22.961	<.001	0.068	0.011	0.057	6.024	<.001
GVA_per_capita	1200.068	43.154	0.331	27.809	<.001	-175.471	4.172	-0.434	-42.057	<.001
Population_density	-0.009	0.001	-0.105	-9.366	<.001	0.002	0.000	0.241	24.807	<.001
Port_dummy	9.928	1.374	0.079	7.228	<.001	-2.512	0.133	-0.179	-18.912	<.001
Small regions	R	R2	Adjusted R2	S.E		R	R2	Adjusted R2	S.E	
	0.421	0.177	0.177	11.843		0.531	0.282	0.281	4.668	
	Beta	S.E.	Stand. Beta	t-value	Significant	Beta	S.E.	Stand. Beta	t-value	Significant
Const.	-12.088	1.085		-11.144	<.001	20.420	0.428		47.765	<.001
time_trend	-0.155	0.030	-0.062	-5.110	<.001	-0.331	0.012	-0.312	-27.700	<.001
Wind_speed	0.509	0.080	0.074	6.374	<.001	-0.916	0.031	-0.317	-29.082	<.001
Precipitation	0.086	0.015	0.062	5.751	<.001	0.037	0.006	0.064	6.322	<.001
Temperature	0.484	0.033	0.164	14.691	<.001	0.062	0.013	0.050	4.797	<.001
GVA_per_capita	44.145	16.328	0.036	2.704	0.007	9.337	6.436	0.018	1.451	0.147
Population_density	0.007	0.000	0.230	18.900	<.001	0.001	0.000	0.117	10.301	<.001
Port_dummy	6.221	0.309	0.236	20.135	<.001	-2.086	0.122	-0.187	-17.130	<.001

Table 4: Impact of port’s presence on local air pollution

Large regions	Mortality rate					Life expectancy				
	R	**R2**	**Adjusted R2**	**S.E**		**R**	**R2**	**Adjusted R2**	**S.E**	
	0,350	0,123	0,122	2,533		0,584	0,341	0,340	2,802	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	8.920	0.229		39.010	<.001	78.974	0.253		312.186	<.001
time_trend	0.039	0.006	0.075	6.435	<.001	0.132	0.007	0.198	19.710	<.001
Wind_speed	0.417	0.021	0.245	20.243	<.001	0.141	0.023	0.065	6.201	<.001
Precipitation	-0.030	0.004	-0.079	-7.096	<.001	-0.042	0.005	-0.086	-8.978	<.001
Temperature	-0.081	0.006	-0.172	-14.677	<.001	-0.116	0.006	-0.192	-18.944	<.001
GVA_per_capita	-10.083	2.244	-0.063	-4.494	<.001	45.900	2.482	0.225	18.492	<.001
Population_density	0.000	0.000	-0.026	-2.198	0.028	0.000	0.000	0.029	2.736	0.006
Port_dummy	0.161	0.064	0.029	2.522	0.012	1.053	0.071	0.149	14.902	<.001
GHG_TOTAL	0.002	0.001	0.053	4.327	<.001	0.002	0.001	0.035	3.331	<.001
$PM_{2.5}$	-0.013	0.006	-0.032	-2.311	0.021	-0.090	0.006	-0.178	-14.632	<.001
Small regions	**R**	**R2**	**Adjusted R2**	**S.E**		**R**	**R2**	**Adjusted R2**	**S.E**	
	0.418	0.175	0.174	1.956		0.673	0.453	0.452	2.127	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	11.388	0.208		54.843	<.001	74.990	0.226		332.051	<.001
time_trend	0.107	0.005	0.258	20.317	<.001	0.026	0.006	0.047	4.501	<.001
Wind_speed	-0.059	0.014	-0.052	-4.180	<.001	-0.257	0.015	-0.170	-16.848	<.001
Precipitation	0.001	0.002	0.006	0.562	0.574	0.018	0.003	0.060	6.763	<.001
Temperature	0.006	0.006	0.012	1.013	0.311	0.123	0.006	0.190	20.481	<.001
GVA_per_capita	-65.730	2.699	-0.327	-24.356	<.001	144.114	2.935	0.537	49.101	<.001
Population_density	-0.001	0.000	-0.101	-8.060	<.001	-0.001	0.000	-0.122	-11.956	<.001
Port_dummy	0.017	0.054	0.004	0.324	0.746	0.800	0.058	0.138	13.739	<.001
GHG_TOTAL	-0.015	0.002	-0.092	-7.707	<.001	0.024	0.002	0.110	11.315	<.001
$PM_{2.5}$	0.023	0.005	0.059	4.628	<.001	-0.089	0.005	-0.170	-16.323	<.001

Table 5: Impact of port’s presence on local health conditions

4.2 The effect of traffic size and specialization

As shown in Table 6, total port traffic has a significant and positive effect on GHG emissions for both small and large regions. The quantity of cargo and passengers[2] handled at ports is thus contributing to local air pollution. It is not the case for $PM_{2.5}$, which confirms the prior findings of Table 4. Interestingly, the average ship turnaround time (ATT) significantly and positively accentuates air pollution. In most cases (except large regions / GHG), this goes along with a significant and positive effect of population density and a negative effect of belonging to an Emission Control Area (ECA). This confirms the findings of Ducruet and Itoh (2022) about the evolution and determinants of ATT at world container ports between 1977 and 2016, whereby city size accentuates ship times and therefore pollution. On the offshore side, solutions such as virtual arrival, vessel speed reduction, inter-terminal barge shuttles, and berth allocation systems are used to lower ATT (Alamoush et al., 2020), just like underground transport, urban area bypass, modal split, automated door systems, truck appointment systems, and connectivity platforms on the onshore side to avoid queuing and congestion.

The use of cold ironing[3] is a widely applied remedy to air pollution (Gonzalez-Aregall et al., 2018), alongside improvements in the productivity of cargo handling vehicles. The role of ECA zones is confirmed, except for large regions / GHG. When it comes to traffic types, their influence is always negative for large regions. For small regions, solid bulks accentuate GHG emissions, while passenger/vehicles and liquid bulks favor $PM_{2.5}$ emissions. This is in accordance with practice, since such traffics produce Volatile Organic Compounds (VOCs) like from bulks during handling and storage. 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,

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[2] In this study, the use of ship tonnage capacity allows measuring cargo and passenger traffic based on the same unit (Gross Registered Tons, GRT).

[3] Cold ironing is known by a variety of names, including shore power, shore-side power, shore-side electricity (SSE), high-voltage shore connection (HVSC), onshore power supply (OPS), shore-to-ship power, and alternative maritime power.

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 Trozzi and Vaccaro, 2000). Temperature clearly accentuates both pollutions while wind speed lower them, for both regional levels.

Cruise shipping is one notable cause of $PM_{2.5}$ emissions (Lloret et al., 2021), which increased by 25% between 2019 and 2023 in Europe, compared with 9% in SO_x and 18% in NO_x emissions (Day, 2023). The EU has made it mandatory for Member States to install shore power facilities in ports by 2025. There are many initiatives in several port cities: cold ironing for ferries (Gothenburg, Hamburg), cruise liners (Amsterdam, Barcelona, Marseille, Le Havre, Livorno), passenger service vessels (Oslo, Venice), barges and other cargo vessels (Antwerp) (Bergqvist and Monios, 2019). As underlined by Iris and Lam (2019), cold ironing "can be very influential for cruise ports because large cruise ships require a huge amount of power since many passengers stay on board during hoteling".

When it comes to health, total traffic accentuates both mortality and life expectancy for large regions, while it accentuates mortality and reduces life expectancy for smaller regions, which is a reasonable result (Table 7). Average turnaround time increases mortality and decreases life expectancy, which is also conform with experience. GVA per capita does the opposite; a decrease of mortality and increase of life expectancy. This indicates that economic development may promote environmental awareness and medical levels, thereby improving health. Such a result is valid for both small and large regions. Another important result is the fact that $PM_{2.5}$ lowers life expectancy for all regions, and increases mortality for large regions only.

	GHG emissions					Exposure to PM2.5				
Large regions	**R**	**R2**	**Adjusted R2**	**S.E**		**R**	**R2**	**Adjusted R2**	**S.E**	
	0,527	0,277	0,275	62,744		0,588	0,346	0,344	5,063	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	-181.393	8.644		-20.985	<.001	23.664	0.697		33.928	<.001
time_trend	-1.374	0.203	-0.097	-6.753	<.001	-0.189	0.016	-0.157	-11.484	<.001
Wind_speed	0.553	0.733	0.011	0.755	0.451	-0.837	0.059	-0.204	-14.149	<.001
Precipitation	0.741	0.134	0.074	5.538	<.001	0.040	0.011	0.047	3.705	<.001
Temperature	3.137	0.184	0.249	17.057	<.001	0.128	0.015	0.120	8.644	<.001
GVA_per_capital	1290.853	76.757	0.267	16.817	<.001	-109.231	6.193	-0.267	-17.637	<.001
Population_density	-0.006	0.002	-0.049	-3.464	<.001	0.002	0.000	0.204	15.056	<.001
ECA_zone	23.085	2.469	0.149	9.348	<.001	-2.108	0.199	-0.160	-10.577	<.001
ATT	0.717	0.345	0.036	2.080	0.038	0.101	0.028	0.060	3.636	<.001
Traffic_LN	8.801	0.700	0.295	12.569	<.001	-0.235	0.056	-0.093	-4.165	<.001
Container_share	-48.679	8.302	-0.120	-5.863	<.001	-2.347	0.670	-0.068	-3.504	<.001
Liquidbulk_share	-37.104	6.796	-0.108	-5.459	<.001	-2.358	0.548	-0.081	-4.301	<.001
Passenger_share	-75.676	6.342	-0.308	-11.932	<.001	-1.223	0.512	-0.059	-2.390	0.017
Solidbulk_share	-4.907	6.650	-0.016	-0.738	0.461	-3.527	0.537	-0.138	-6.574	<.001
Small regions	**R**	**R2**	**Adjusted R2**	**S.E**		**R**	**R2**	**Adjusted R2**	**S.E**	
	0.611	0.373	0.370	14.935		0.541	0.293	0.290	3.552	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	-52.043	3.143		-16.557	<.001	16.988	0.748		22.723	<.001
time_trend	-0.168	0.064	-0.046	-2.627	0.009	-0.209	0.015	-0.258	-13.759	<.001
Wind_speed	0.956	0.158	0.099	6.063	<.001	-0.489	0.037	-0.227	-13.047	<.001
Precipitation	0.079	0.028	0.043	2.851	0.004	0.026	0.007	0.064	3.947	<.001
Temperature	0.653	0.081	0.156	8.051	<.001	0.108	0.019	0.115	5.578	<.001
GVA_per_capital	14.809	32.512	0.008	0.456	0.649	-51.237	7.733	-0.128	-6.626	<.001
Population_density	0.013	0.001	0.294	17.170	<.001	0.002	0.000	0.217	11.912	<.001
ECA_zone	-4.766	0.884	-0.108	-5.392	<.001	-1.076	0.210	-0.109	-5.119	<.001
ATT	0.622	0.100	0.118	6.213	<.001	0.118	0.024	0.100	4.935	<.001
Traffic_LN	2.720	0.192	0.350	14.157	<.001	-0.143	0.046	-0.082	-3.127	0.002
Container_share	-14.522	2.247	-0.129	-6.463	<.001	-2.842	0.534	-0.113	-5.319	<.001
Liquidbulk_share	-1.515	1.702	-0.017	-0.890	0.373	0.274	0.405	0.014	0.677	0.498
Passenger_share	-11.888	1.466	-0.202	-8.111	<.001	0.794	0.349	0.060	2.276	0.023
Solidbulk_share	6.575	1.714	0.076	3.837	<.001	-2.018	0.408	-0.105	-4.952	<.001

Table 6: Impact of traffic size and specialization on local air pollution

Large regions	Mortality rate					Life expectancy				
	R	R2	Adjusted R2	S.E		R	R2	Adjusted R2	S.E	
	0.386	0.149	0.146	2.344		0.625	0.390	0.388	2.441	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	9.533	0.377		25.309	<.001	77.741	0.392		198.203	<.001
time_trend	0.020	0.008	0.040	2.515	0.012	0.072	0.008	0.120	8.889	<.001
Wind_speed	0.167	0.028	0.101	5.971	<.001	0.130	0.029	0.063	4.444	<.001
Precipitation	-0.016	0.005	-0.047	-3.218	0.001	-0.036	0.005	-0.084	-6.791	<.001
Temperature	-0.042	0.007	-0.096	-5.804	<.001	-0.122	0.007	-0.228	-16.260	<.001
GVA_per_capita	-21.223	3.053	-0.128	-6.951	<.001	45.141	3.179	0.221	14.199	<.001
Population_density	0.000	0.000	-0.017	-1.044	0.297	0.000	0.000	0.078	5.775	<.001
ECA_zone	0.532	0.094	0.100	5.646	<.001	-1.559	0.098	-0.237	-15.878	<.001
ATT	0.003	0.013	0.004	0.210	0.833	-0.036	0.013	-0.042	-2.661	0.008
Traffic_LN	0.153	0.027	0.149	5.740	<.001	0.360	0.028	0.285	12.946	<.001
Container_share	-3.503	0.312	-0.251	-11.227	<.001	-1.709	0.325	-0.100	-5.259	<.001
Liquidbulk_share	-2.072	0.255	-0.175	-8.110	<.001	-2.207	0.266	-0.151	-8.296	<.001
Passenger_share	-1.533	0.241	-0.181	-6.353	<.001	-0.509	0.251	-0.049	-2.026	0.043
Solidbulk_share	-2.553	0.250	-0.246	-10.222	<.001	-2.496	0.260	-0.196	-9.596	<.001
GHG_TOTAL	0.001	0.001	0.028	1.686	0.092	0.002	0.001	0.053	3.724	<.001
PM2_5	-0.062	0.007	-0.153	-8.628	<.001	-0.115	0.007	-0.229	-15.299	<.001
Small regions	R	R2	Adjusted R2	S.E		R	R2	Adjusted R2	S.E	
	0.462	0.213	0.209	1.636		0.662	0.438	0.435	1.587	
	Beta	**S.E.**	**Stand. Beta**	**t-value**	**Significant**	**Beta**	**S.E.**	**Stand. Beta**	**t-value**	**Significant**
Const.	9.387	0.385		24.353	<.001	77.958	0.374		208.433	<.001
time_trend	0.126	0.007	0.355	17.342	<.001	0.112	0.007	0.275	15.907	<.001
Wind_speed	-0.103	0.018	-0.110	-5.796	<.001	-0.104	0.017	-0.096	-6.004	<.001
Precipitation	0.008	0.003	0.043	2.548	0.011	0.008	0.003	0.039	2.672	0.008
Temperature	-0.020	0.009	-0.048	-2.193	0.028	0.082	0.009	0.175	9.377	<.001
GVA_per_capita	-22.391	3.589	-0.128	-6.239	<.001	39.072	3.482	0.195	11.220	<.001
Population_density	0.000	0.000	-0.102	-4.926	<.001	0.000	0.000	-0.084	-4.814	<.001
ECA_zone	0.798	0.098	0.186	8.159	<.001	-1.143	0.095	-0.232	-12.035	<.001
ATT	-0.009	0.011	-0.018	-0.833	0.405	-0.015	0.011	-0.025	-1.355	0.176
Traffic_LN	0.018	0.022	0.023	0.808	0.419	-0.044	0.021	-0.050	-2.077	0.038
Container_share	-1.192	0.249	-0.109	-4.780	<.001	0.871	0.242	0.069	3.597	<.001
Liquidbulk_share	0.055	0.186	0.006	0.296	0.767	0.049	0.181	0.005	0.272	0.785
Passenger_share	-0.580	0.162	-0.101	-3.569	<.001	0.710	0.158	0.107	4.505	<.001
Solidbulk_share	0.993	0.189	0.118	5.256	<.001	0.741	0.183	0.077	4.041	<.001
GHG_TOTAL	-0.010	0.002	-0.103	-4.883	<.001	0.029	0.002	0.258	14.487	<.001
PM2_5	0.114	0.009	0.261	13.180	<.001	-0.018	0.008	-0.036	-2.133	0.033

Table 7: Impact of traffic size and specialization on local health conditions

The results by traffic types do not show any particular logic, as the observed trends contradict each other between small and large regions and between mortality and life expectancy. Yet, and except for large regions, traffic categories improve health conditions, with a negative sign for mortality and a positive side for life expectancy. Among these types, the share of containers is the most influential, probably due to the aforementioned nature of container traffic that is, to concentrate in more advanced regions (Ducruet and Itoh, 2016) – here, in healthier regions. The belonging to an ECA zone provides results in total opposition with reality, as a positive dummy (1) aggravates health conditions, and the absence of an ECA zone (0) improves it.

4.3 Towards a typology of port regions

4.3.1 Factor analysis

A factor analysis provides a global view of all regions and variables (Figure 2). Interestingly, the scatter plot of variables along the two main factor sis highly similar between large and small regions. It is important, as it demonstrates the quality and robustness of data and trends, which are stable across geographic scales. Groups of variables emerge, like in the upper-right quadrant with total traffic, container share, GDP per capita, and ATT, together with GHG emissions and population density. This confirms that container traffic concentrates in large ports as well as urban regions (Ducruet et Itoh, 2016). Exposure to PM2.5, especially for small regions, is also projected on the right side of the first axis (horizontal), thereby participating to this profile of “port metropolis”.

Natural elements only have a marginal role on pollution and health in the figure. In terms of health, mortality rate and life expectancy are opposed in a logical manner. Moreover, mortality is close to liquid and solid bulks in the upper-left quadrant. Although there is no possibility to establish a causal relationship, such a result confirms that bulks produce VOCs during cargo handling (coal, grain, ores, oil) that spread throughout the city’s atmosphere and get mixed with urban pollution. Without protection, conveyor belts carrying coal or iron ore between port and plants provoke leaks and emissions during loading and unloading. For tankers, VOCs (methane and nonmethane) contribute to GHG emissions. Among them, the heavier components (nonmethane) contribute to photochemical oxidants like ozone, which affects human health, food production, and the environment.

Despite intermodalism permitted by containerization, container traffic generates important flows of heavy-duty vehicles within the port, across the city, and with the hinterland. In Europe, 75% of cargo flows occur by road (Eurostat, 2019), due to the geographic, logistical, and political difficulties implementing a modal shift towards short-sea shipping. These flows generate congestion, against which it is possible to fight through the use of various systems to track trucks and better regulate traffic, but also booking systems, automated door systems, as well as inter-terminal barge or rail shuttles (Gonzalez-Aregall et al., 2018). For inland navigation, modal shift is an important option, but also the bypass of urban areas with a dedicated freight line or underground freight transport (Visser, 2018). At container terminals, “green concessions” (Notteboom et Lam, 2018) between port and operators may include modal split obligations to favor green modes (van den Berg et de Langen, 2014).

Average ship turnaround time (ATT) is close to total traffic and GHG emissions in a logical way, since the bigger the demand (population density, GVA per capita), the bigger the traffic and pollution. This explains the launch of automated mooring systems to reduce ATT, during which ships continue to burn fuel. In the case of ro-ro terminals, Alamoush et al. (2020) estimated that such systems allow to reduce CO2 emissions due to mooring by 97%. In addition, berth allocation and planning can also contribute to lower ATT. According to Styhre and Winnes (2019), this reduction applies well to containerships, which operate on a regular basis contrary to bulk ships (Styhre et al., 2017).

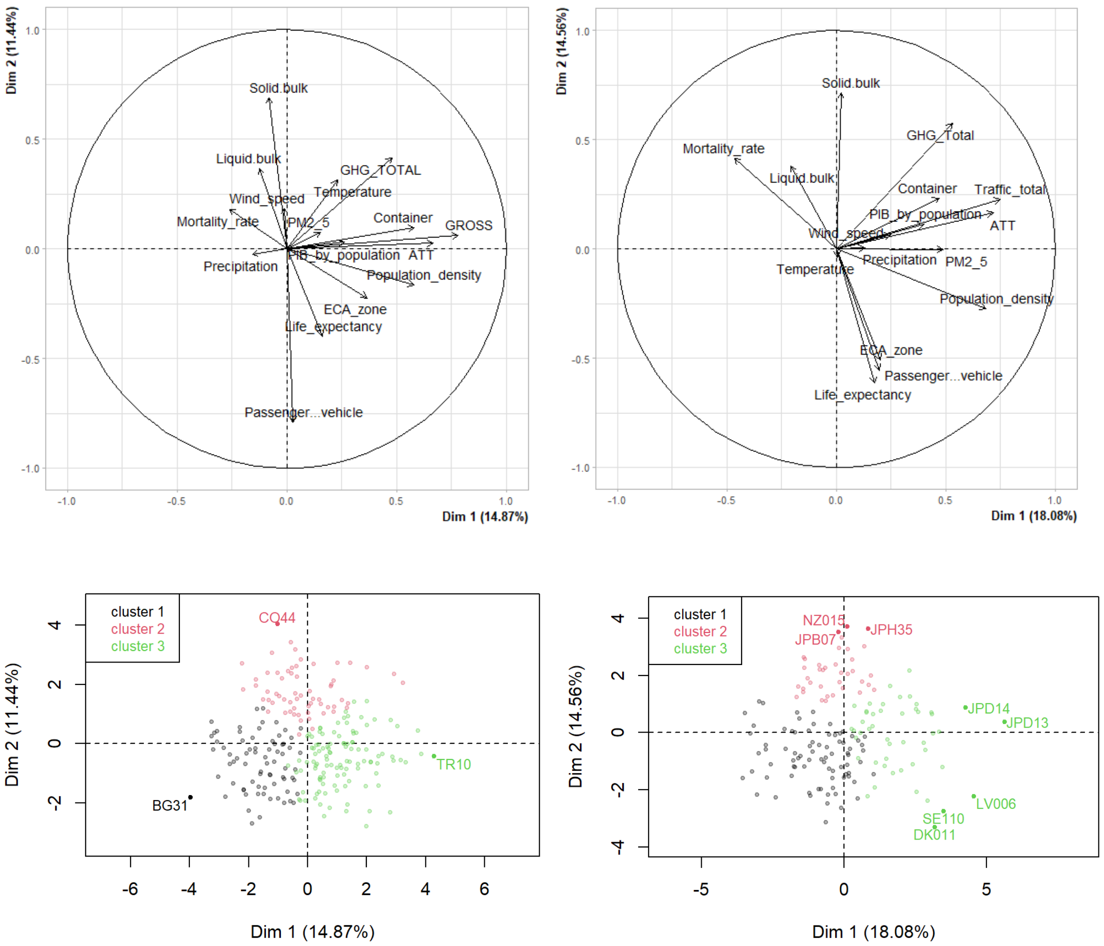

Figure 2: Factor analysis and classification in 2018

N.B. 245 large regions (left) and 164 small regions (right)

At last, life expectancy is grouped with ECA zone and passenger/vehicle traffic. This makes sense if we consider that North Europe and North America are old industrial countries benefiting from mature healthcare systems. The importance of passenger traffic can be explained by the density of short-sea shipping in Northern Europe for instance (i.e., Baltic Sea). A disaggregation by traffic subtypes is necessary to check the specific role of cruise compared with ferries, ro-ro, and vehicle traffic, as a path for further research.

4.3.2 Clusters of port regions

The great similarity of our results for small and large regions made it possible to categorize them in the same way, regardless of tiny differences (Table 8). Those three clusters of port regions bear nearly the same scores on all variables. Dynamic port regions are those with the lowest mortality rate and highest life expectancy, while they rank high for population density and GDP per capita. They carry the largest traffic volumes and specialize in the most valued traffic, i.e., containers, far ahead other regions. Their ATT is the longest, probably due to their role as market concentrations and important settlements, and they have the highest average number of regions belonging to an ECA zone.

	Large regions			Small regions		
	Dynamic port regions	Intermediate port regions	Critical port regions	Dynamic port regions	Intermediate port regions	Critical port regions
GHG_emissions	3.31	2.35	3.60	2.28	1.38	2.57
PM2.5	0.94	0.92	0.95	1.01	0.87	0.94
Mortality_rate	0.99	1.06	1.09	0.99	1.09	1.22
Life_expectancy	1.00	1.00	0.98	1.00	0.99	0.98
Density_population	1.14	0.65	0.69	1.01	0.40	0.28
GDP_capita	1.00	0.85	1.02	1.02	0.79	0.97
Total_traffic	17.64	13.27	16.29	17.01	13.60	15.61
Containers	24.95	6.31	9.48	22.45	1.58	9.96
Liquid_bulks	12.64	16.57	27.24	12.33	14.25	24.05
Passengers_vehicles	49.16	43.60	12.29	47.64	51.56	21.93
Solid_bulks	7.99	8.50	41.76	9.04	3.62	34.01
ATT	12.74	7.22	10.49	11.50	6.71	8.41
ECA_zone	0.46	0.27	0.20	0.32	0.28	0.05
Wind_speed	1.00	0.93	1.13	1.21	1.06	1.04
Precipitations	0.91	1.14	0.96	1.25	0.90	0.90
Temperature	1.01	0.96	1.06	1.01	1.02	1.00

Table 8: Results of the hierarchical clustering analysis, 2018

At the opposite side of the coin, critical port regions have the most important GHG emissions and mortality rates, together with the lowest life expectancy. They do handle important traffic volumes, but this traffic is mainly composed of solid and liquid bulks, i.e., lower-valued and more polluting traffic. What is more, such regions are not so much part of ECA zones, given their lowest number of regions in this category.

Between those two types, intermediate port regions do not witness a specific profile.

They rank high only for a few variables, such as passenger and vehicle traffic. More importantly, they have the lowest GHG and $PM_{2.5}$ emissions, traffic volume, GDP per capita, and ATT of all regions. Given their low population density, it is possible to infer that such a profile corresponds to peripheral regions using passenger transport to connect with the "core" regions. The following cartography allows us to identify which regions compose these clusters on the map, and possible spatial regularities.

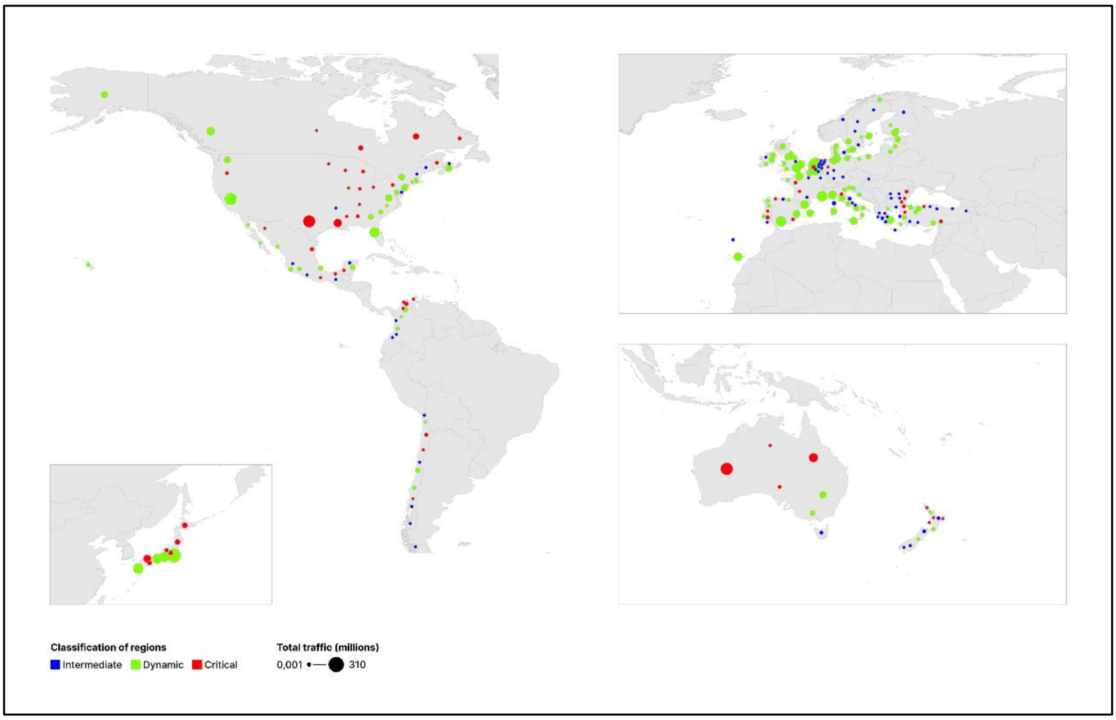

Figure 3: Typology of large port regions in 2018

The typology of large regions (Figure 3) reveals interesting spatial patterns across the globe. First of all, dynamic port regions concentrate in Europe. Globally, Europe is recognized as a fertile ground for actions promoting port city sustainability. 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 & 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. In North America, dynamic port regions are found along the Eastern seaboard (Halifax – Miami) and the Pacific coast (Alaska – Mexico), comprising of the most urbanized states like New York, Florida, California, as well as British Columbia in Canada.

Comparatively, critical port regions in Europe concentrate along the Atlantic Ocean and the Black Sea, with only a couple of them in North Europe and in Italy. Elsewhere, this category includes the mining regions of Australia, the periphery of Japan (e.g., Hokkaido), and the interior regions of USA and Canada. Like for Australia, two large regions specialized in bulks also belong to this category, namely Texas and Louisiana.

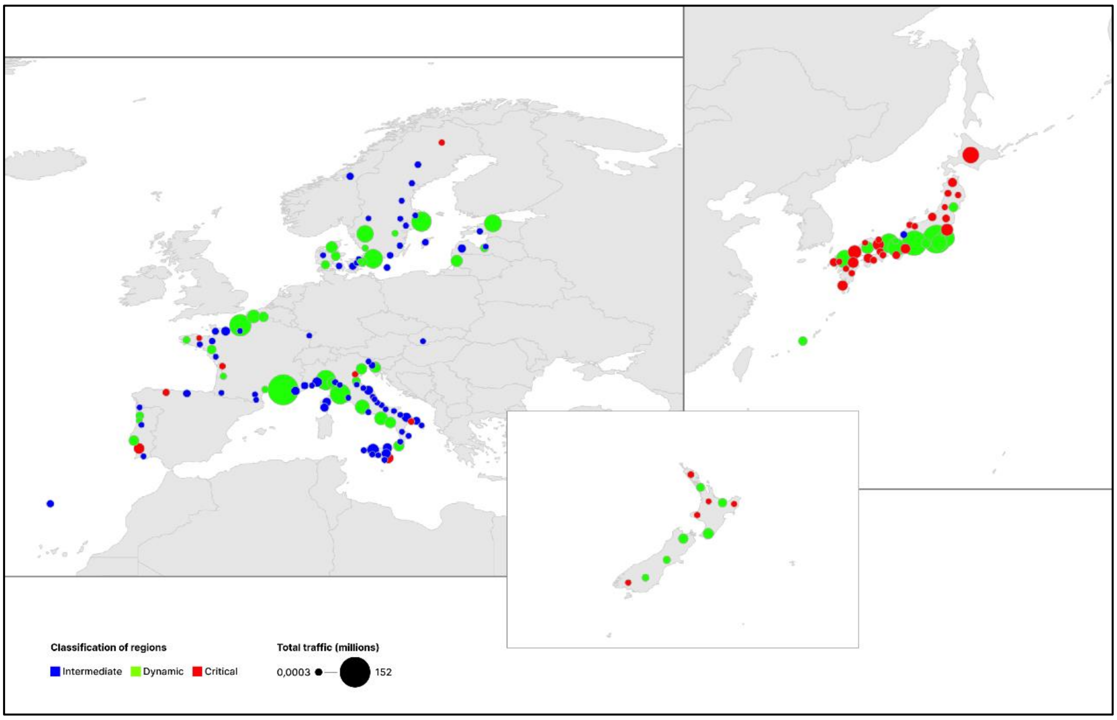

Figure 4: Typology of small port regions in 2018

For small regions (Figure 4), data was available only for parts of Europe, New Zealand, and Japan. This explains at least in part the country bias whereby most critical port regions concentrate in Japan. The rest of Japan is composed of dynamic port regions situated along the so-called megalopolis from Fukuoka to Tokyo. Such a pattern for Japan is likely to be explained by the ageing population, which accentuates mortality rates outside of the megalopolis.

In Europe, the critical port region with the maximum traffic is Alejento, with the port of Sines having developed a container hub out of a heavy industrial growth pole. Most traffic goes to dynamic regions, such as Marseille-Fos (Bouches-du-Rhône), Le Havre and Rouen (Seine-Maritime), France's two largest industrial and container ports. Other cases include Gothenburg (Västra Götaland), Malmö and Stockholm in Sweden, Tallinn in Estonia, and Klaipeda in Lithuania. Italy concentrates a sheer number of dynamic port regions, containing the large ports of Genoa, Savona and La Spezia (Liguria), but also Lazio (Civitavecchia), Naples and Salerno.

5. Discussion and conclusion

This research provides the first-ever empirical analysis of the relationships between port activities, environment, and health from an international perspective. A thorough review of the existing literature revealed that only a few studies actually measured the health impacts of ports (and their industrial areas) at the local level, compared with studies of environmental impacts. This work is challenging due to the fact that it does not measure actual port pollution, but rather, the presence of port(s) and port activities in general. Local measures of pollution and health are, in turn, not specific to ports, and correspond to much wider areas (in surface) than the port or the port city. Finding a link between port activities and local pollution/health thus makes the study successful in many ways.

By putting together data from the OECD and the Lloyd's List at the level of subnational regions, main results confirm that port regions pollute more than non-port regions, in terms of GHG emissions, while port regions are also specific by their above-average mortality rates. The analysis based on the port dummy confirms that the presence of port(s) increases GHG emissions but not PM2.5 emissions, mainly due to winds. Beyond the port dummy, traffic size and average turnaround time increase pollution, in accordance with the hypotheses. Belonging to an Emission Control Area (ECA) lowers local pollution as predicted, a trend which is valid at both territorial levels.

The analysis of pollutions (GHG and $PM_{2.5}$) together with traffic volume and traffic types corroborate practice in many ways, as GHG increase mortality in all cases, and $PM_{2.5}$ lowers life expectancy, although it is not proved that such pollutions come from the port itself. It is one future task of further research to complement traffic with ship pollution data, at the condition that more information on engine and fuel types can be made available.

Last but not least, this research detected similar types of regions at both territorial levels, small and large regions, confirming the robustness of data and spatial patterns. As regional data is more widely available for large regions than for small regions, our results could not be directly comparable between the two levels. Additional efforts are needed to gather data at the level of small regions. Nevertheless, the OECD Territorial Database also provides data on metropolitan areas, which constitute another interesting research pathway. At such a detailed level of analysis, it will be possible to include more many variables on port city topography and morphology for instance, and use data on urban congestion, such as the Tom-Tom Index[4]. While maritime traffic itself can be further disaggregated by ship types (i.e., crude oil, chemicals, tanker, general cargo, port services, cruise, ferries, etc.), connectivity indicators measuring the situation of port cities in the global maritime network can also be utilized.

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Appendix 1: Descriptive statistics for the year 2018

Variable	Unit	Large regions					Small regions				
		Mean	Median	Max.	Min.	Std. Dev.	Mean	Median	Max.	Min.	Std. Dev.
Mortality_rate	LQ	1.04	1.03	1.86	0.51	0.17	1.95	1.80	4.91	0.28	0.92
Life_expectancy	LQ	1.00	1.00	1.04	0.87	0.02	0.93	0.92	1.41	0.58	0.16
GHG_emissions	LQ	3.09	2.97	6.49	0.68	1.15	1.09	1.08	1.55	0.70	0.16
PM2.5	LQ	0.94	0.94	1.86	0.28	0.17	0.99	0.99	1.02	0.94	0.01
Density_pop	LQ	0.88	0.71	3.35	0.01	0.62	0.57	0.40	3.74	0.05	0.54
GDP_hab	LQ	0.96	0.89	3.51	0.34	0.34	0.91	0.88	3.51	0.51	0.29
ATT	days	10.49	10.90	15.50	1.00	3.58	8.66	8.94	15.19	0.50	3.70
Containers	%	15.39	4.88	77.43	0.00	20.13	10.32	2.64	75.86	0.00	16.06
Liquid_bulks	%	17.48	11.99	97.00	0.00	19.80	15.96	6.91	100.00	0.00	21.17
Passengers_vehic	%	38.28	34.27	100.00	0.00	31.13	43.25	42.25	100.00	0.00	32.54
Solid_bulks	%	16.56	7.17	100.00	0.00	23.32	12.60	4.73	100.00	0.00	17.74
Total_traffic	LN	15.97	16.74	19.55	6.95	2.61	15.18	15.72	18.84	5.82	2.53
ECA_zone	Dummy	0.33	0.00	1.00	0.00	0.47	0.24	0.00	1.00	0.00	0.43
Wind_speed	Knots	1.01	1.00	2.72	0.45	0.28	1.10	1.09	1.87	0.34	0.30
Precipitations	0.01 inch	1.00	0.88	5.77	0.00	0.71	1.01	0.84	6.75	0.03	0.86
Temperature	F°	1.01	1.01	1.53	0.42	0.12	1.01	1.01	1.31	0.66	0.10