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The impact of northern Adriatic ports container throughput on air quality environmental parameters

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JEL Classification: Q51, Q56, R40, D71

Abstract

This paper seeks to highlight the impact of the increasing container throughput in northern Adriatic ports on air quality. A comparative analysis of air quality is given, which consist of certain environmental parameters at selected measuring stations near the container terminals of the northern Adriatic ports Rijeka, Trieste, Koper, and Venice. The parameters were analyzed based on a limited amount of air quality monitoring data for the port areas. As the port transport sector increases pollutant emissions, the results of these analyzes can also be used to take appropriate measures to reduce these particulate matter emissions. The aim of this paper is to determine the impact of increasing the container throughput within the ports of the northern Adriatic Sea on air quality, based on certain environmental parameters related to the shipping or delivery of containers by road. The results of the research, based on available data, have shown that the increase in container throughput of the northern Adriatic ports has not decreased the air quality of urban areas of the respective port cities. The air quality value of the northern Adriatic ports is substantially below the limits set by the EU Air Quality Directive (2008/50), thus it does not affect the health of the inhabitants of the analyzed cities.

Introduction

The ports of the northern Adriatic, i.e., Rijeka, Trieste, Koper, and Venice, have extremely favorable locations that make them attractive to the countries of Central Europe (Petrlić & Pavletić, 2019). Also, the ports of the northern Adriatic are of great importance for the movement of freight in South-eastern Europe. Those ports have huge potential to become a main route from the Far East to Europe. Excellent land connections from the ports to Central Europe is available via the developed Trans-European Transport Network and the Mediterranean Corridor, which connects the Danube region with the Adriatic Sea and the Mediterranean Sea (Vilke, Brčić & Kos, 2017).

The container terminal in the Port of Rijeka has an extensive impact on the increase in the land transport in the city of Rijeka, which sometimes leads to congestion in the city center (Kegalj, Traven, & Bukša, 2018). In the last five years, throughput at the container terminal has been increasing steadily (Port of

Rijeka Authority, 2021). The main benefit of higher container throughput is greater profits, but it can also have a negative impact on the air quality of the city (Trozzi & Vaccaro, 2000; Corbett et al., 2007; Verhoeven, 2010; Urbanyi-Popiołek & Klopott, 2016; Johansson, Jalkanen & Kukkonen, 2017; Liu & Hoon Lim, 2017; Gobbi, di Liberto & Barnaba, 2020; Sorte et al., 2020). A similar problem has been found in Canadian port cities, which further illustrates the impact of ships and fuel quality on air pollution (Anastasopolos et al., 2021).

According to the European Directive (European Parliament and Council of the European Union, 2008), limit values have been set for the parameters discussed in this paper. In certain Asian and European ports, plans of action are being established that are used to promote "green" ports in terms of the functional activities of port operations (Browne et al., 2012; Russo and Comi, 2012; Lam & Notteboom, 2014).

This paper is a continuation of the research presented at the conference of the International Association of Maritime Universities and published in AGA 21 conference book (AGA21, 2021). In this updated version, the research was extended to include a comparative analysis for major port cities in the northern Adriatic, as the problem of excessive pollutant emissions in the port area is identical to most ports (Merico et al., 2020, 2021). The research problem of the paper arises from the formulation of several research questions, for example:

- RQ1: Does the increase in container terminal cargo volume have a direct negative impact on air quality in the respective port cities?

In view of this research problem, the following hypothesis has been set: The increasing throughput of a container terminal has a negative impact on the air quality near the terminal. By installing a monitoring station at the terminal, more accurate readings for the source of the pollution could be achieved.

Geographical and transport aspects of the northern Adriatic ports

The Adriatic Sea has a very favorable position in Europe, with the shortest access to the world's seas through the Gulf of Trieste and Rijeka, while it has extensive potential as the main link for the southern European traffic flow (Vilke, Brčić & Kos, 2017). Industrially developed countries of Europe and Asia are two complementary worlds connected with northern Adriatic traffic flow. Also, it is an optimal route for connecting Africa and Australia with Europe.

There is a significant and potential economic and demographic market in the narrower Central European area that could use the traffic flows of the Northern Adriatic as an optimal route for the flow of goods from the Mediterranean and the rest of the world. According to data in Table 1, the voyage from East Asian ports to Central Europe through the Northern Adriatic is 10 days shorter, considering that the route is about 2000 nautical miles shorter than the main route, while the voyage from North American ports is slightly longer. Therefore, the ports of Rijeka and Trieste are much closer to the main ports of the world, which significantly affects their development potential compared to the North Sea ports.

Table 1. Sea distances (in nautical miles) between the ports of Rijeka, Trieste, and Hamburg with other significant global ports (Vilke, Brčić & Kos, 2017)

Port	Rijeka	Trieste	Hamburg
Port Said	1254	1294	3551
Bombay	4315	4340	6620
Shanghai	8555	8589	10 855
New York	4785	4814	3535
Singapore	6275	6308	8585
Hong Kong	7734	7768	10 029

According to the data in Table 2, the land route from the ports of the northern Adriatic to various major European cities is about 500 km shorter than the route through Western Europe (Vilke, Brčić & Kos, 2017).

Table 2. Railway distance (in kilometers) of the northern Adriatic and North European ports to certain Central European economically significant destinations (Vilke, Brčić & Kos, 2017)

Railway	Rijeka	Koper	Trieste	Hamburg	Rostock
Budapest	592	634	626	1406	1166
Bratislava	602	650	639	1022	980
Prague	806	854	810	686	644
Vienna	580	599	584	990	984
Linz	557	549	517	911	923
Munich	563	599	527	777	876

Important land connections from Central European countries to the Adriatic seaports intersect in the area of Croatia, Slovenia and Italy with other important traffic flows leading from Western and Central Europe to South-Eastern Europe and the Middle East.

The impact of container throughput of the Port of Rijeka and related land traffic on air pollution

The City of Rijeka conducts air quality measurements in various locations in the city, especially in places where increased air pollution is expected. Therefore, the measurements are carried out in 16 locations, which include the industrial part of the city and streets with heavy traffic, i.e., high traffic congestion. In 2018, air pollution measurements determined that Primorsko-goranska County were in the 1st category of air quality, which in other words means it has clean air or negligible pollution (Primorsko-Goranska County, 2019). The scientific project CEKOM Connected traffic, with its activities, includes the implementation of the measurements of the environmental parameters with an explanation and associated methodology (measurement method / suitable equipment). The obtained data is to be used to monitor and assess air quality and, subsequently, lead to the proposal and implementation of measures to prevent and reduce air pollution (Project study – Connected Traffic., 2020).

The railway and road traffic connecting the container terminal of Rijeka with the hinterland

The implementation of Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 had a positive impact on increasing the share of rail freight traffic in the Port of Rijeka (European Parliament and Council of the European Union, 2009). The container terminal in the Port of Rijeka could experience a further increase in rail capacity in 2020 thanks to the development of a new intermodal terminal and the expansion of the single-track Sušak tunnel to two tracks.

Table 3. Share of land transport in the Port of Rijeka container transshipment. Created by the authors from statistical data (Adriatic Gate Container Terminal, 2021)

Year	Port Transshipment	Road transport	Railway transport	Lorries	Wagons
	(TEU)	(TEU)	(TEU)	%	%
2015	161.883	124.725	37.158	77.05	23
2016	177.401	132.984	44.417	74.96	25
2017	210.377	147.173	63.204	69.96	30
2018	227.375	162.422	64.953	71.43	28,6
2019	271.817	168.643	103.174	62.04	38
2020	344.091	176.746	126.880	58.3	41.7

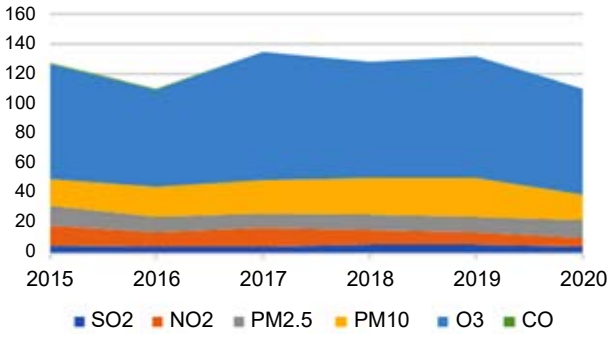
The data from Table 3 clearly show the share of land transport in container handling in the Port of Rijeka in the period from 2015 to 2020. According to this data, a positive trend in the growth of port transshipment, and the road and rail transport, can be observed during the period from 2015 to 2020.

The increase in freight transport by road, in the period from 2015 to 2020, is more than 42%, while at the same time freight transport by rail increases by more than 300%. A positive indicator of the further development of the Port of Rijeka is also the total transport of freight by rail of more than 40%.

An overview of air quality environmental parameters at the Rijeka 2 monitoring station

By directly acting on the source and quantity of pollutants, a reduction can be achieved. One of main air quality indicators, that can negatively impact human health is particulate matter 2.5 (PM2.5) and particulate matter 10 (PM10). According to the European Commission, despite regional differences within the European Union, transport causes 25% of pollutants in cities, while industry causes 15% of pollutants. (European Commission, 2015). The analysis of the measured parameters (SO2, NO2, PM2.5, and PM10) shows a normal concentration of pollutants, i.e., it does not affect negatively the quality of life of a nearby residential area. The measurement of environmental parameters considered the data from the measuring station, which is in the immediate vicinity of the Port of Rijeka.

According to Figure 1, the values of all parameters fall in the period from 2015 to 2016, while the values increase slightly in the next three years. With the occurrence of the pandemic COVID-19, the values of all the parameters decrease, as there were significant restrictions on population movement,



* Note: PM10 for 2019 is the estimated value.

Figure 1. Mean values of the collected parameters 2015–2020. Created by the authors using data from (Croatian Agency for Environment and Nature, 2021)

which was also reflected in a decrease in transport. In addition, the increase in port capacity did not have a significant impact on air quality in the urban area. Moreover, a significantly higher proportion of containers were shifted to rail, which also leads to a decrease in air pollution.

Possibilities for obtaining more relevant values of environmental parameters

In port cities, it is difficult to assess the impact of port activities on the environment and air quality because pollution in port cities is usually mixed. Part of the pollution is due to port activities, while part of the pollution comes from industrial areas, traffic, etc. (Merico et al., 2021). During the activities of the connected traffic project, considering that obtaining information based on the collected data is a complex process, it was found that the system for measuring environmental parameters in urban areas is used at several levels. With the appropriate equipment, the environmental parameters can be measured directly or indirectly.

In the case of direct measurement via sensors, the pollutant levels are measured at stations outside of the pollution center. Therefore, it is not possible to determine with certainty the impact of traffic or port activities to air pollution. Although the direct measurement method provides information about the amount of pollutants at the measurement point, it is not possible to determine the proportion of pollutants that originate from motor vehicles due to the dispersion of air gasses. By attaching a mobile sensor to public transport vehicles or commercial vehicles, the success of the direct measurement method can be achieved. Within the target area, such a measurement method can provide information on the pollutant footprint and the change or dynamics of the movement of the footprint.

The highest level of functionality is achieved by the indirect measurement method. By positioning sensors at the source of the pollution and using computer models based on the dynamics of the movement, the most relevant data on the impact of traffic on the environment is obtained. The sensors are installed at the container terminal, or at the operating shore, to measure the pollution caused by the ships and handling equipment. Sensors are also installed at the entrance and exit ramp for trucks. The application of computer models, based on the movement dynamics recorded by video analysis and sensors, will provide information on the impact of traffic and its flow on environmental parameters and pollution (Project Study – Connected Traffic, 2020).

Impact of the northern Adriatic ports container throughput on air quality

With the increase in shipping in recent years, the share of cargo traffic has also increased considerably. As a result, many port cities are expanding the capacity of their port areas in terms of infrastructure, as well as logistics. The increase in cargo handling in ports leads to a higher utilization of port machinery and a greater number of ships, which also pollute the air in the vicinity of container terminals since most ports do not have the ability to connect ships to the terminal's power grid. This lack of a linkage is one of the main causes of air pollution in port cities, while in some cases

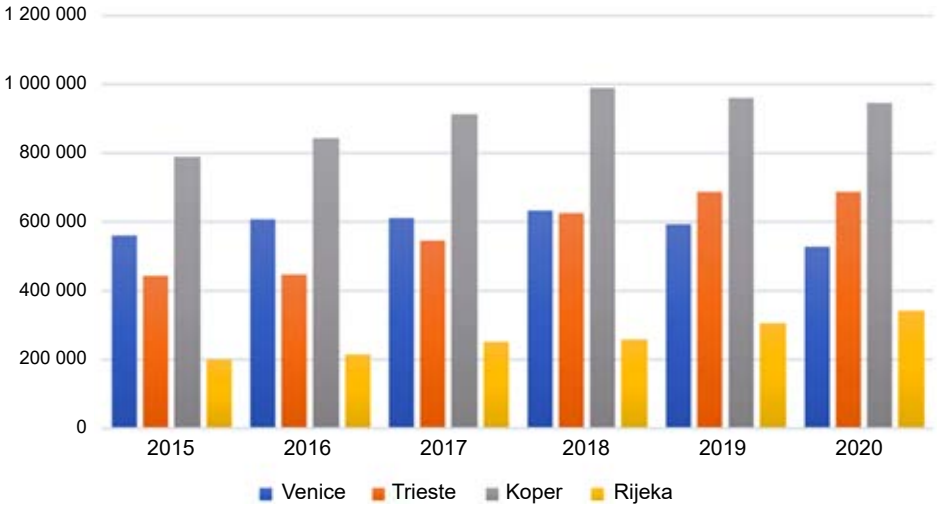


Figure 2. Container throughput of the northern Adriatic ports (Port of Venice, 2021; Port of Koper, 2021; Port of Rijeka, 2021; Trieste Marine Terminal, 2021)

air pollution from road traffic is less than that from vessels.

The container throughput of the northern Adriatic ports is of great economic importance, especially for the city of Koper, which leads in the total number of containers handled. The ports of Trieste and Venice follow the Port of Koper in terms of the number of containers handled, while the Port of Rijeka has a much lower turnover, but it is the only one to show a constant increase over the last 6 years. The number of TEU handled in the northern Adriatic ports for the period 2015–2020 is shown in Figure 2.

In the period 2018–2019, the ports of Koper and Venice recorded a decrease in throughput by approximately 3% and 6%, respectively, while the ports of Rijeka and Trieste saw an increase in throughput by approximately 15% and 9%, respectively, over the same period. It should also be noted that the container throughput in the ports of the northern Adriatic increased in the observed period, while it stagnated in 2020, except for the Port of Rijeka.

NAPA – The Northern Adriatic Ports Association

The NAPA was founded in 2010 by the ports of Koper, Trieste, Venice, and Ravenna with the aim of strengthening the position of the ports and promoting the northern Adriatic region to the international business community and EU institutions. Eight months later the Port of Rijeka joined the Association (Port of Venice, 2017).

Figure 3 shows the location of the important ports on the northern Adriatic in different countries. Although each port operates under its own specific conditions, the geographical location and the hinterland are the cause of the common features of the ports.

The NAPA ports handle more than 100 million tons of cargo every year. This involves mainly general cargoes, containers, cars, ores and minerals, fossil fuels, chemicals, and other types of cargo (North Adriatic Ports Association, 2013). Thanks to a wide variety of logistics services and a well-developed transport network, the NAPA has a perfect multimodal access to major European markets. The nearby Mediterranean corridor provides direct access to 500 million European consumers.

The four ports joined forces to promote the northern Adriatic route and present it as an alternative solution for northern European ports. The Association also offers support in the development of maritime and deep-sea connections, cruise ships, environmental protection, safety, and information technology. In addition to mergers, the ports of NAPA offer cooperation and investment in coordinated planning of the road, rail, and maritime infrastructure and the harmonization of regulations and procedures in port services (North Adriatic Ports Association, 2013).

According to the data in Table 4, the North Sea ports have one main traffic direction. Although the ports of the northern traffic flow are significantly further away, their container traffic is steadily increasing due to numerous logistical advantages such as a developed road and rail network, modern cargo handling technology, etc.

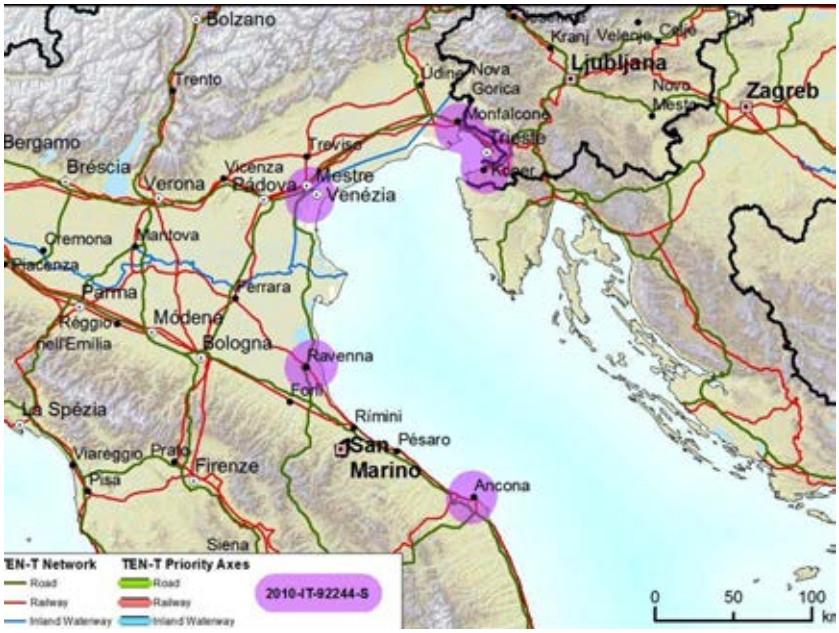


Figure 3. Location of northern Adriatic ports with multimodal links (European Commission, 2013)

Table 4. Comparison of container traffic in European ports, 2019 (Statistics | Eurostat, 2021)

Port	Container Traffic (in million TEUs)
Rotterdam	13.49
Antwerp	11.68
Hamburg	9.28
NAPA Ports	2.76
Zeebrugge	0.48
Marseille	1.46

Regulated pollutants

The monitored environmental parameters used in the analysis were collected from the environmental authorities for the observed cities. The data collected by the monitoring stations cover the period from 2015 to 2019. The monitoring stations are located near ports and in urban areas of the cities. The measured variables used in this analysis to measure air pollution are listed in Table 5, and the parameters were observed using annual average values. In addition, for certain years, an estimate based on annual averages had to be made because the monitoring station was down or data was not available for the required period.

Estimated emissions in the northern Adriatic ports

The increase in the cargo handling in the northern Adriatic ports leads to an increase in greenhouse gas emissions. This is due to the increased activity of cargo handling machinery in ports, road and rail traffic, arrival of ships, etc. Therefore, the exposure of residents in port cities is higher. Given the increasing demand for goods in the last five years, it is necessary to study the air quality in the major ports of the northern Adriatic region. The observed emissions of PM10, PM2.5, NO2, and O3 in the northern Adriatic ports were analyzed based on the data collected by the regional air quality monitoring stations.

As shown in Figure 4, the second largest port by container throughput, Venice, has the highest NO2 emissions, while the Port of Trieste has comparable levels, followed by Koper and Rijeka with significantly lower pollutant levels. Venice is also leading in PM10 and PM2.5 emissions in the indicated period, while the other ports show comparable values. After Venice, PM10 emissions are most pronounced in Trieste, Koper, and Rijeka until 2017, when Rijeka reached Trieste. In the following years, Rijeka experienced a significant increase in the PM10 pollution, while the other cities experienced small and uneven decreases.

The emissions of PM2.5 indicators are much less pronounced in the observed cities. Venice still records higher pollution compared to other cities, while Trieste and Rijeka record only small decreases during the elaborated period. Due to the lack of data from the monitoring station, Koper is not included in the calculation of PM2.5 indicators. For the last observed parameter O3, Trieste is not included in the calculation due to the lack of data. Other cities have similar and inconsistent values, but Rijeka and Venice have slightly higher deviations than Koper. Moreover, Rijeka generally showed a slight increase, while Venice contrasts with this observed period.

Comparative analysis of NAPA ports air pollution

With regards to the studied northern Adriatic ports, the Port of Rijeka has by far the lowest container throughput, i.e., it has the lowest traffic volume. However, the Port of Rijeka is the only one of the ports studied where traffic volumes have increased continuously during the analyzed period. Moreover, extensive infrastructure investments should increase the potential for this trend to continue. It is, therefore, expected that a further increase in

Table 5. List of measurements employed in the analysis (ARPA FVG, 2021; Citta' di Venezia, 2021; DHMZ, 2021; Slovenian Environment Agency, 2021)

Port	Site	City	Location	Measured Variable	Time Resol.	Being Year	End Year
Trieste	ARPA FVG	Trieste	via Pitacco – Trieste	PM10, PM2.5, NO2	annual average	2015	2019
Venice	ARPAV	Malcontenta	Via Lago di Garda	PM2.5			
	ARPAV	Venzia	Sacca Fisola	NO2, O3			
Rijeka	DHMZ	Rijeka	Ul. Franje Belulovića	PM10, PM2.5, NO2, O3			
Koper	ARSO	Koper	Brolo square	PM10, NO2, O4			

ARPA FVG, Agenzia Regionale per la Protezione dell'Ambiente del Friuli Venezia Giulia; ARPA V, Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto; DHMZ, Croatian Meteorological and Hydrological Service; ARSO, Slovenian Environment Agency.

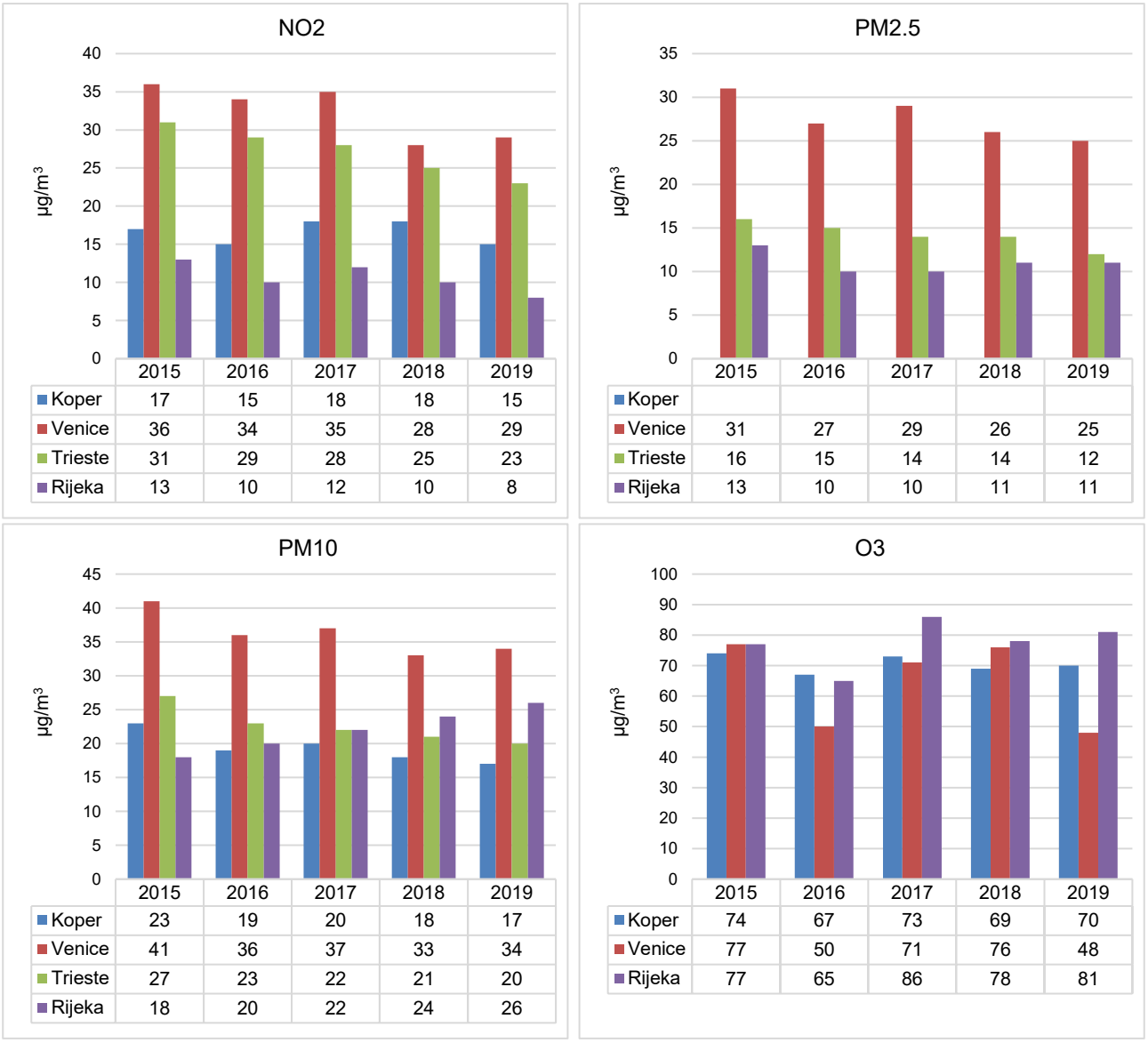


Figure 4. Annual emissions in some northern Adriatic ports (ARPA FVG, 2021; Citta' di Venezia, 2021; DHMZ, 2021; Slovenian Environment Agency, 2021)

container traffic will have an impact on the reduction of air quality at the source of pollution.

The analysis of the ecological parameters based on the available data of the year 2019 shows that the area near the Port of Rijeka has three times less NO2 emissions than the areas near the observed Italian Ports of Trieste and Venice, and almost doubled emissions compared to the Port of Koper. However, the PM10 measurements show that the area near the Port of Rijeka has about 35% higher emissions than the area near the Port of Koper and around 20% more than the area near the Port of Trieste, while the Port of Rijeka has slightly lower PM10 emissions than the Port of Venice. No data on PM2.5 emissions were available for the Port of Koper; however, data was available for other observed ports and the Port of Rijeka recorded almost the same PM2.5 emissions as the Port of Trieste. In Venice, doubled air pollution with PM2.5 was measured in comparison to the Port of Rijeka. Ozone emissions in the Port of Rijeka were the highest of all the observed ports, except for the Port of Trieste (no data available). Thus, the measured levels in the vicinity of the Port of Rijeka were 13% higher than those at the Port of Koper, while 40% lower O3 emissions were measured at the Port of Venice.

Conclusions

Most major port cities face similar problems of air pollution from passenger or cargo ships, especially from port operations and transportation. Therefore, the increase in port activities expands the risk of negative impacts of pollutant emissions, which

can endanger the health of residents. This article provides an overview of air quality in port cities of the northern Adriatic area based on a comparative analysis and an answering of research questions. The data collected from the monitoring stations were used to create an analysis that considers the impact of each port in the northern Adriatic area, i.e., of their activities and traffic on the local population. In addition, to prove the hypothesis, the appropriate methodology for this area of research was used.

Air pollution in the vicinity of the Port of Rijeka does not exceed the limit values. Although, according to certain parameters, it has similar air pollution to ports with significantly higher container throughput. The reason for the existing amount of air pollution is the nearby vicinity of the city center with its higher volume of vehicles and the industrial plants near the port. Therefore, it is quite difficult to determine the exact impact of the port on air pollution in the surrounding residential areas. The Port of Koper, like the Port of Rijeka, is located in close proximity to the city center or residential areas. Koper is a smaller city in terms of population and does not have as many problems with city traffic as Rijeka. Although the Port of Koper is the leading port on the northern Adriatic in terms of the number of containers transshipment (almost three times more than the Port of Rijeka), and a large part of the cargo is dispatched and delivered by land, pollutant emissions are still below the limits.

While the Port of Trieste is not located in the immediate vicinity of a city center, as is the case with the ports mentioned above, it has an urban center that certainly contributes to air pollution. Therefore, in addition to the high traffic concentrations near the port, and the industrial areas as well, it is difficult to determine the impact of increasing container traffic on air quality. Like the Port of Trieste, the Port of Venice is not close to the city center, but still has a large cargo throughput and an industrial area is located nearby. Although it is a very popular tourist and cruise destination, the monitoring stations are located much further away from the old town, which is the most visited area by tourists. Considering all the ports monitored, the Port of Venice had the worst air quality according to the parameters analyzed.

As there is no further distribution of measuring stations, the pollutants from the ports, urban traffic, and industry have accumulated in the observed area. The proportion structure of the analyzed pollutants is not known, it is impossible to conclude that one of the factors has no influence on the resulting amount of pollutants. Given the available data, it is very difficult to estimate the impact of the port handling on air quality in nearby residential areas. Therefore, this research based on available data has shown that the increase in container throughput in the northern Adriatic region has not reduced air quality in residential areas of port cities. The northern Adriatic ports are significantly below the limits set by the EU Air Quality Directive (2008/50), so the health of the inhabitants of the observed cities should not be endangered in terms of air quality.

Further research will focus on a more accurate determination of air pollution in port cities, which uses data from the measuring stations at the source of the pollution or in the immediate vicinity of the port. In addition, mobile measuring stations should also be included to obtain more meaningful air quality readings.

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