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A Comparative Study Among Black Sea Ports Using Geospatial Data

Abstract. *The Black Sea Plateau is one of the most diverse areas on the continental shelf. Starting from that, the research aims to identify the competitiveness model of Black Sea's ports in order to develop partnership among Black Sea's countries for a sustainable development of Black Sea economic model. To achieve the main purpose of the research, geospatial data gathered from the Marine Traffic Platform was used, which is an online platform that monitors the marine traffic around the world. In this respect, the sample of analysis consists of 36 ports which are activating in the Black Sea Plateau from all the five countries (Romania, Turkey, Ukraine, Georgia, Russia). The data were analysed using appropriate machine learning techniques in order to identify the economic models existing in the Black Sea Plateau. As it was expected, the main results present diversity among Black Sea's ports, but, at the same time, it can be stated that there are several common directions that can be applied to develop a more sustainable economic model.*

Keywords: *Black Sea, competitiveness, GIS, sustainability, marine traffic.*

JEL Classification: O18, O57, Q25.

1. Introduction

The Black Sea Plateau represents one of the most diverse fishing areas on the continental shelf. This is not only due to the climatic variations in the countries opening to the Black Sea, but also to the geopolitical context of the countries opening to this plateau. For example, Romania and Bulgaria are two member countries of

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NATO and the European Union, Turkey is a country with an interesting feature, from the point of view of geographical location, being part of both Europe and Asia. On the other hand, in the north of the Black Sea, an open conflict smoulders between two Slavic countries, Russia and Ukraine, to which we add a pro-European country, Georgia, but in which, at the moment, Russian influences make their presence felt.

That is why the research aims to identify the patterns of existing large traffic in the Black Sea, as well as the typology of the ports with exit to this continental plateau. The original element of the research is represented by the use of GIS data for maritime traffic monitoring, the data being collected from the Maritime Traffic platform.

Based on the results of this research, it is possible to identify the directions of sustainable development on the geospatial competitiveness carried out at the level of the Black Sea. In addition, by identifying the maritime patterns of the promontories with access to the Black Sea, partnerships can be consolidated/realised at the level of the Black Sea plateau.

The paper is structured as follows. The Literature Review section presents the relevant papers on this topic. The next section describes our approach and the collected data. The result and discussion are presented in the next section, where the main findings are presented. The paper ends with conclusions and future work.

2. Literature Review

At the level of the Black Sea plateau, there are significant differences from the perspective of economic activity and environmental impact. Balcilar et al. (2017) studied the level of pollution in the Black Sea plateau, using two air quality assessment stations, one located on the border between Bulgaria and Turkey, representing the western part of the Black Sea, and another, located in the East between Russia and Georgia. The results show that a higher level of pollution is recorded on the western flank of the Black Sea, as a result of the increased density of industrial activities in countries, such as: Romania, Bulgaria, Turkey, or even Ukraine. Given the geopolitical context at the level of the Black Sea, with two countries integrated into the European Union (Romania, Bulgaria), two countries in a state of war since 2014 (Russia, Ukraine) and two other countries on the border between Europe and Asia (Turkey and Georgia), the Black Sea Commission has limited powers in developing and complying with a common program to promote sustainable development in the Black Sea Plateau (Avoyan et al., 2017). However, Strokal et al. (2023) state that if there is no intervention through sustainable development policies, the future of the Black Sea is not a sustainable one, the level of pollution will increase constantly as a result of the wastewater tartar circuit. Andreyeyeva et al. (2018) state that a unitary strategy cannot be developed at the level of the economies of the Black Sea plateau, because each economy is emerging in its own way presenting its own particularities. Thus, despite these peculiarities present at the level of the 6 economies present at the Black Sea plateau (Romania, Bulgaria, Turkey, Georgia, Russia and Ukraine), there is a causal relationship between domestic loans to the private sector (DPS) and per capita household consumption expenditure (HCE) for five of the economies present at the level of the Black Sea (Turkey, Georgia, Bulgaria, Romania, and Ukraine) (Lu and Dilanchiev, 2023). Miron et al. (2019) highlight the importance of Black Sea ports for Romanian's trade flows of goods and services. In addition, the Black Sea presents diversity from the perspective of water flow variation, at the level of a day, but also at the level of a calendar year, which leads to significant differences in terms of the economic activity carried out in the Black Sea (Yuce, 1993). This fact can be considered a cause for the differences regarding the evolution of fish species in the Black Sea basin during the 90s (Kideys et al., 1999). The evolution of fish species has also been influenced by climate change, particularly by the phenomenon of water warming (Oguz et al., 2003). For example, Maximov et al. (2011) carried out a quantitative study, using data on the catch from the Black Sea, in the period 1990-2009. The main result of this research confirms that approximately 82-90% of the total catch of commercial fishing agents are pelagic species (sprat, anchovy, mackerel).

Considering this existing diversity at the level of the Black Sea, Bulgaria wants to adopt a strategy regarding the protection of water quality, in particular, in the ports of Burgas and Varna, ports with a high transport and industrial flow, which have a negative impact on water quality (Quynh et al., 2011). This factor also negatively affects the production of mussels in the Bulgarian area of the Black Sea, being a consequence of the improper use of the Black Sea basin (Klisarova et al., 2020).

On the other hand, the Russian Federation focused on the development of the infrastructure for tourism and yachting in the Black Sea Coast of Russia, but also on encouraging economic agents present in the area of the Black Sea Coast of Russia through fiscal facilities (Dreizis and Potashova, 2018; Gontar, 2020). According to Grădinaru and Ioan (2012), all Black Sea's countries should offer fiscal facilities to develop green entrepreneurship. Moreover, according to Gradinaru (2013), economic growth is directly influenced by ecosystem services. However, in order to be able to monitor the effect of measures to increase sustainability at the level of the states of the Black Sea plateau, Otoiu and Gradinaru (2018) propose a composite indicator capable of measuring the level of sustainability, the Environmental Sustainability Index (ESI).

3. Data and Methodology

To achieve the main objective of this research, two methods of quantitative statistical analysis were used, through unsupervised learning: *Principal Component Analysis* (PCA) and *K-means Clustering Algorithm*. Principal Component Analysis is a frequently used method for reducing a large number of variables to a small number of selected variables, that explain most of the variation of the entire data set (Pathak et al., 2010). In addition, through the basic property of this method, to include in a main component as many correlated variables as possible, and the main components show a low level of correlation, it will contribute to increasing the robustness of the results regarding the identification of the maritime specificity of the ports of in the Black Sea.

The first principal component within a feature set $X_1, X_2, ..., X_p$ represents the most significant normalised linear combination of these features, expressed as $Z_1 = \varphi_{11}X_1 + \varphi_{21}X_2 + ... + \varphi_{p1}X_p$, where it exhibits the highest variance among all possible combinations. Normalisation in this context implies that the sum of the squares of the loadings, $\varphi_{11},...,\varphi_{p1}$, equals one, i.e., $\sum_{j=1}^{p} \varphi_{j1}^{2}$. These loadings, which contribute to the first principal component, are collectively known as the principal component loading vector, denoted by φ_1. To ensure that the variance remains meaningful, the loadings are constrained so that their sum of squares is unity, preventing the possibility of inflating the variance through arbitrarily large loadings. Additionally, it is assumed that each variable in X has been centered to a mean of zero, which is essential for focusing on variance. This leads to the goal of identifying the linear combination of sample feature values that maximises sample variance, adhering to the normalisation constraint, thus effectively solving an optimisation problem where the objective is to maximise the variance of this linear combination (James et al., 2013, p. 375).

In this study, *Principal Component Analysis* is used to ensure cluster consistency. Later, based on the resulting main components, and based on the homogeneity of the data from these components, clustering is performed using the *K-means* method. This algorithm has an iterative approach and it determines the optimal number of clusters by the minimisation of the variation at the cluster level and the maximisation of the variation between the clusters. Let $C_1, ..., C_K$ represent the sets that contain indices corresponding to the observations within each cluster that adhere to two fundamental principles:

1. The union of all sets, $C_1 \cup C_2 \cup ... \cup C_K$, encompasses all observation indices from 1 to n, ensuring every observation is included in at least one of the K clusters.
2. The intersection of any cluster set with itself, $C_k \cap C_k$, is empty for each k, indicating that clusters do not overlap and no observation is part of more than one cluster.

The core principle of *K-means* clustering is to achieve a clustering outcome where the within-cluster variation is minimised. This variation for a cluster C_k is quantified by a measure $W(C_k)$, which evaluates how much the observations within a cluster deviate from each other. The objective, therefore, is to minimise the total within-cluster variation across all clusters, expressed mathematically as: $min_{C_1,.......,C_k}\{\sum_{k=1}^{K} W(C_k)\}$. This equation embodies the goal of partitioning observations into K clusters in a manner that reduces the total within-cluster variation to the lowest possible extent.

To operationalise this, it is essential to define what constitutes within-cluster variation. Although various definitions are possible, the most prevalent approach is to use the squared Euclidean distance. Specifically, the within-cluster variation for C_k is defined as: $W(C_k) = \frac{1}{|C_k|}\sum_{i,i' \in C_k}\sum_{j=1}^{p}(x_{ij} - x_{i'j})^2$. This formula reiterates the aim to organise observations into *K* clusters such that the cumulative within-cluster variation, aggregated over all clusters, is minimised (James et al., 2013, p. 386-387).

Starting from the main objective of the research, to identify the maritime and economic profile of the Black Sea ports, the sample consisted of all the sea ports operating in the Black Sea plateau.

The data were collected from the Marine Traffic platform (https://www.marinetraffic.com/) for the period between July 21, 2023 and July 30, 2023. Marine Traffic is an online platform for live monitoring of maritime traffic based on geospatial data. It monitors in real time the volume of passengers, the ships transiting each port, but at the same time it also provides information on the economic operators in each port. In the initial stage, we identified all the ports that carry out economic activities in the Black Sea area, and then we collected relevant information about them, such as: geographic coordinates (latitude/longitude), the number of ships arriving and departing in each port, as well as the percentage distribution of the various types of vessels that frequent these port facilities (Table 1).

Table 1. The variables used in the research

Variable	Unit of measure	Description[1]
Arrivals	Number	The total number of arrival ships
Departures	Number	The total number of departures ships
Containers	Percentage	Vessel designed to carry containers
Dry Breakbulk	Percentage	Vessel designed to carry goods that are not in a container (loose, palletized etc.)
Dry Bulk	Percentage	Vessel designed to carry free-flowing unpacked solids in bulk
RO-RO	Percentage	Vessel with ramp designed to carry roll-on/roll-off cargo (goods and containers that can be driven)
LPG Carriers	Percentage	Vessel designed to carry Liquefied Petroleum Gas (LPG)
Wet Bulk	Percentage	Vessel designed to carry liquid cargo
Other Markets	Percentage	Specialised or miscellaneous vessel types that don't fit neatly into the other categories
Supporting Vessels	Percentage	Vessel designed to provide support
Passenger	Percentage	Vessel designed to carry more than 12 passengers
Fishing	Percentage	Vessel designed for fishing
Pleasure	Percentage	Vessel designed for recreation

Source: own work.

[1] United Nations, Economic Commission for Europe, Codes for types of means of transport, Recommendation No. 28, Revision 3, 12 July, 2010

In order to achieve the research objectives, the daily values were aggregated by calculating the average for each variable. The mean is representative throughout the sample, with moderate asymmetry being present for each variable. In addition, the reference period of the data is representative, as it covers all sectors of activity of the sampled ports, including tourism activity carried out during the summer season. The sample consists of 36 statistical units, represented by Black Sea ports in all countries opening to this sea: *Constanța*, *Sulina*, *Mangalia*, *Midia* (Romania), *Yevpatoriya*, *Sevastopol*, *Chornomorsk*, *Kerch*, *Feodosiya*, *Odessa*, *Yalta*, *Yuzhny* (Ukraine), *Adler*, *Tuapse*, *Kavkaz*, *Sochi*, *Gelendzhik*, *Novorossiys*, *Anapa* (Russia), *Fatsa*, *Samsun*, *Inebolu*, *Hopa*, *Bartin*, *Sinop*, *Zonguldak*, *Trabzon* (Turkey), *Varna*, *Balchick*, *Pomorie*, *Burgas*, *Sozopol*, *Nessebar* (Bulgaria), *Supsa*, *Poti*, and *Batumi* (Georgia).

4. Results and Discussions

The main purpose of this analysis was to identify patterns and to find out the relationships within the data that can be explained with fewer variables than the original dataset.

To calculate the own vectors of each component, the first step was to standardise variables by using z-scores (z_i). This step is particularly important because variables have different units of measurement, and the amplitude of the series is also different from variable to variable. Therefore, the following formula was used for standardisation $z_i = \frac{x_i - \bar{x}}{s}$, where $\bar{x}$ is the sample mean and s is the sample standard deviation.

Later, standardised variables were used in R, through the *factoextra* package, to calculate the eigenvalue values (Table 2).

Table 2. Eigenvalue of each principal components

Dimension	Eigenvalue
Component 1	2.88
Component 2	2.28
Component 3	1.37
Component 4	1.33
Component 5	1.15
Component 6	1.00
Component 7	0.88

Source: own work.

By analysing the eigenvalues, which represent the addition of R^2 coefficients between factors and the variables that enter into its composition, we can admit that there are 6 principal components which have a higher value than 1 and can explain the variation of the entire dataset to a great extent than each variable would do it individually. The seventh component is the only one who has a smaller value than 1, more precisely 0.88 which means that it defines the variation of the dataset to a lesser extent than an individual variable would do. Conversely the first component explains the variation of the dataset significantly, having a value equal to 2.88.

It is of great importance to study the distribution of variables across each principal component. In order to analyse the six principal components, we used a key tool, a correlation matrix, which was used to understand the relationship between variables and their interactions in the context of the principal components. The matrix was created based on variables quality representation at the level of the principal components.

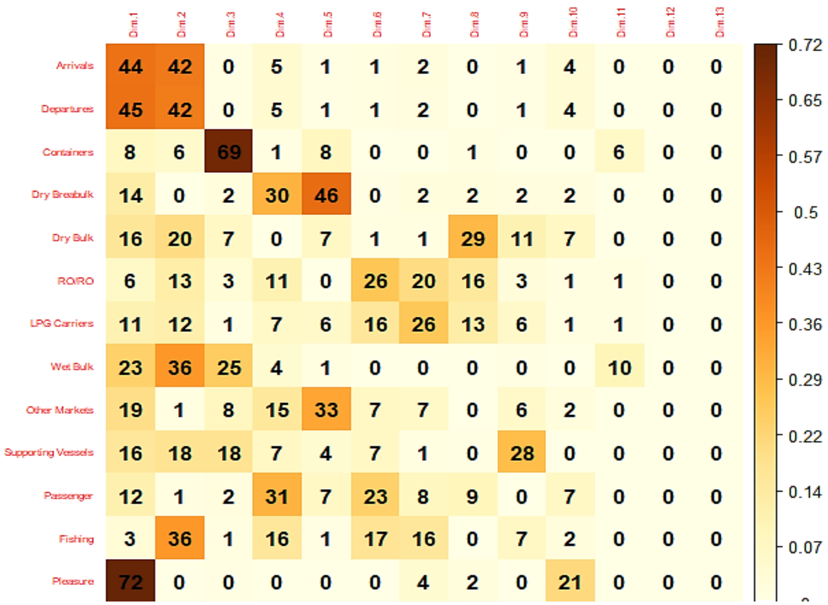

Figure 1. Correlogram of variables and principal components

Source: own work using RStudio.

By the nature of the variables included in each of the components, six distinct phenomena were identified that characterise geopolitical comity in the Black Sea area: shipping dynamics, commercial maritime traffic, maritime traffic of transporting goods, maritime passenger transport, maritime shipment, Roll-on-Roll-off (Figure 1 and Table 3).

Table 3. The distribution of variables on each phenomenon

Dimension	Variables
Shipping dynamics	Arrivals, Departures, Pleasure
Commercial maritime traffic	Fishing, Wet bulk transporting
Maritime traffic of transporting goods	Containers ships, Supporting vessels
Maritime passenger transport	Passengers
Maritime shipment	Dry Breakbulk, Other markets
Roll-on-Roll-off	RO-RO

Source: own work.

At the level of each identified phenomenon, the ports included in the sample were clustered. Using the elbow rule, the optimal number of clusters for each individual component is 3 clusters.

4.1 Shipping dynamics

The first cluster is made up of 3 ports: Sochi, Gelendzhik, and Novorossiysk (Russia).

In the second cluster, there are 10 ports: Constanta, Sulina (Romania), Adler, Anapa (Russia), Samsun (Turkey), Varna, Burgas, Nessebar (Bulgaria), Poti, and Batumi (Georgia).

In the third cluster, there are 23 ports: Mangalia, Midia (Romania), Yevpatoriya, Sevastopol, Chornomorsk, Kerch, Feodosiya, Odessa, Yalta, Yuzhny (Ukraine), Tuapse, Kavkaz (Russia), Fatsa, Inebolu, Hopa, Bartin, Sinop, Zonguldak, Trabzon (Turkey), Balchik, Pomorie, Sozopol (Bulgaria) and Supsa (Georgia) (Figure 2).

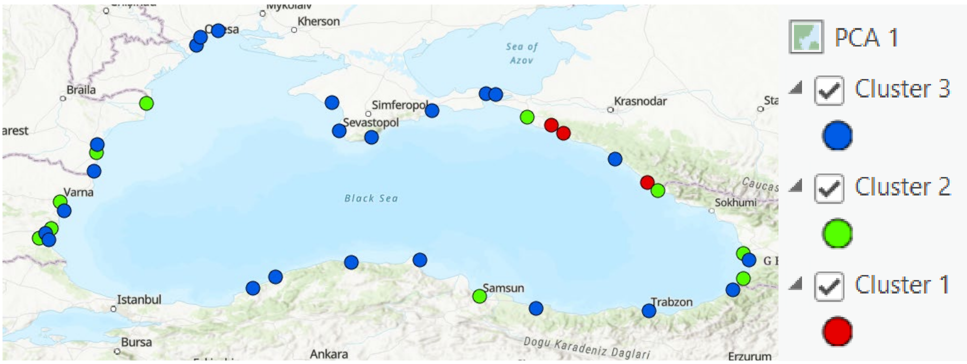

Figure 2. Clusters distribution of shipping dynamics
Source: own work using ArcGIS Pro.

The first cluster has the highest average of arrivals and departures, indicating is the busiest cluster in terms of maritime traffic. The second cluster has moderate levels of arrivals and departures and the third cluster has significantly lower levels of arrivals and departures, compared to the other two clusters (Table 4).

Table 4. The centres of cluster (shipping dynamics)

Cluster/Variable	Arrivals	Departures	Pleasure
1	3014	1175.33	59.56
2	743.4	733.6	24.85
3	84.6	84.86	14.8

Source: own work.

Analysing the pleasure boat means that we can conclude that the first cluster has the highest average of pleasure boats anchored, indicating it is a popular destination for boats which activate in the pleasure market; the second has a moderate level of pleasure boats which anchored and the third cluster has the lowest number of pleasure boats which anchored, fact that indicates it is not a popular choice for boats which activate in the leisure market.

Looking at the clusters and at the ports locations, we can observe that in the first cluster the ports are located in Russia. In the second cluster, there are ports spread across various countries including Romania, Bulgaria, Turkey, and Georgia. In the third cluster, although the ports are spread across various countries, the main ones are from Ukraine and Russia.

Analysing the clusters performances, we can say that in terms of both commercial maritime traffic and pleasure boating the first cluster has the best performance, this region being maritime vibrant. The second cluster has a moderate maritime activity and is relatively popular for pleasure markets. The third cluster has the lowest maritime activity and is not a significant destination for pleasure boats.

In summary, the first cluster is the busiest and the most popular for leisure market. The second is moderately active, and the third cluster has the lowest maritime activity These clusters represent different maritime regions with varying levels of performance and attractiveness to boats and ships. We can conclude that even though Russia has an embargo, all of the ports from the first cluster are from Russia which means that it is the most active country in the Black Sea transport.

4.2 Commercial maritime traffic

The first cluster consists out of 28 ports (Constanța, Sulina, Mangalia, Midia (Romania), Feodosiya, Odessa, Yalta, Yuzhny (Ukraine), Tuapse, Fatsa, Samsun, Inebolu, Hopa, Bartin, Sinop, Zonguldak, Trabzon (Turkey), Anapa, Kavkaz, Sochi, Gelendzhik, Novorossiysk (Russia), Varna, Burgas (Bulgaria), Poti, Batumi (Georgia)), the second cluster 3 ports (Yevpatoriya, Kerch (Ukraine) and Balchik (Bulgaria)) and the third cluster 5 ports (Sevastopol (Ukraine), Pomorie, Sozopol, Nessebar (Bulgaria) and Supsa (Georgia)) (Figure 3).

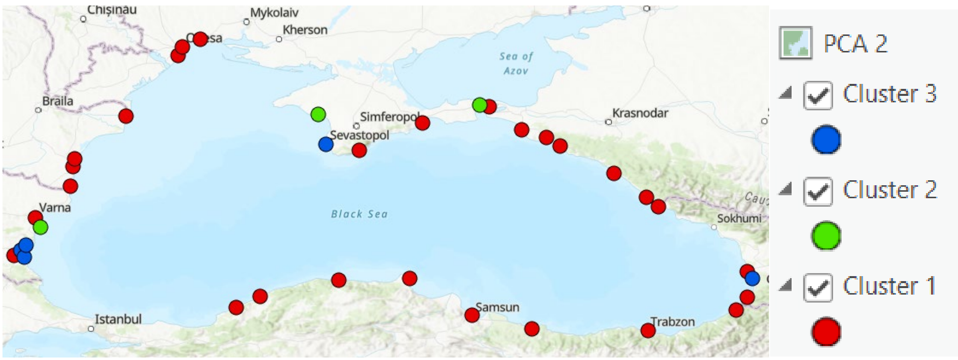

Figure 3. Clusters distribution of commercial maritime traffic
Source: own work using ArcGIS Pro.

The first cluster represents ports with a mixed usage pattern. These ports have a moderate number of fishing boats from the fishing market and some boats involved in transporting wet bulk. They seem to be versatile in their maritime activities.

The second cluster stands out as ports heavily focused on fishing. They have a substantial number of fishing boats from the fishing market but little to no activity in transporting wet bulk. This cluster seems to be primarily driven by the fishing industry.

The third cluster represents ports that are mainly associated with fishing but have a lesser presence of boats transporting wet bulk compared to cluster 1. It might indicate a preference for fishing activities over bulk transport.

Table 5. The centres of cluster (Commercial maritime traffic)

Cluster/Variable	Fishing	Wet Bulk
1	1.19	4.84
2	86.33	0
3	34.41	0

Source: own work.

Analysing the clusters performances, we can say that the first cluster has a moderate activity for both fishing and wet bulk transporting. This cluster seems to strike a balance between fishing and wet bulk transportation, indicating versatility in maritime operations. The second cluster has the high activity in fishing, suggesting it is the most active cluster in this industry. However, it has no presence in wet bulk transport, indicating a specialised focus on fishing. The third cluster also has a substantial activity in the fishing industry but no wet bulk transport, implying a significant fishing activity presence but less diversity in maritime activities (Table 5).

In summary, the second cluster is distinct for its heavy focus on fishing, the third cluster leans toward fishing but with less diversity, while the first cluster demonstrates versatility in both fishing and wet bulk transport. These suggest that these clusters represent different maritime profiles in terms of their primary activities and may cater to different industry demands or have unique economic characteristics.

4.3 Maritime traffic of transporting goods

The first cluster consists of 21 ports: Sevastopol, Kerch, Feodosiya, Yalta (Ukraine), Yuzhny, Adler, Sochi, Gelendzhik, Anapa (Russia), Fatsa, Inebolu, Hopa, Bartin, Sinop, Trabzon (Turkey), Balchik, Pomorie, Sozopol, Nessebar (Bulgaria) and Batumi (Georgia).

In the second cluster, there are 14 ports: Constanța, Sulina, Mangalia, Midia (Romania), Odessa (Ukraine), Tuapse, Kavkaz, Novorossiysk (Russia), Samsun, Zonguldak (Turkey), Varna, Burgas (Bulgaria), Supsa, and Poti (Georgia).

In the third cluster, there is one port: Chornomorsk (Ukraine) and has the following averages: average of containers boats 0 and the average of supporting vessels boats equal to 95.24 (Figure 4).

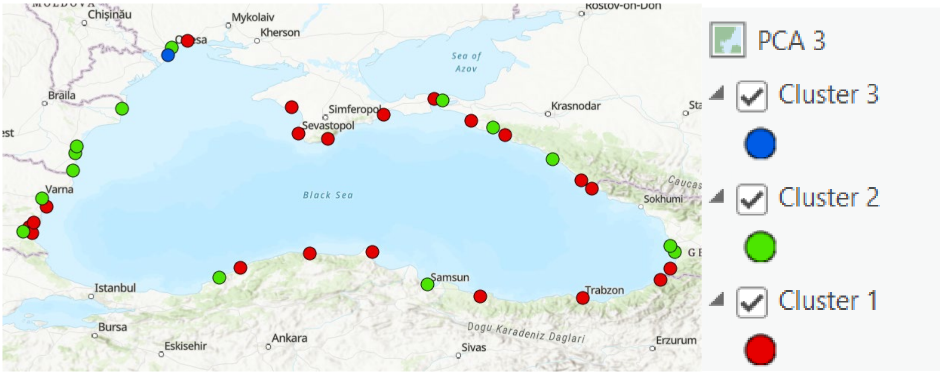

Figure 4. Clusters distribution of maritime traffic of transporting goods

Source: own work using ArcGIS Pro.

The first cluster represents the ports which have a moderate presence of containers and a relatively low presence of supporting vessels. This clusters have some similarities in terms of containers boats and a relatively low presence of supporting vessels.

The second cluster has ports which have also containers, but have a high presence of supporting vessels, indicating a different focus and no need of this type.

In the third cluster Chornomorsk stands out because it has no container activity but a very high presence of supporting vessels. Analysing this fact, we can conclude that Chornomorsk is a port with a lot of big ships which need provisioning (Table 6).

Table 6. The centres of cluster (maritime traffic of transporting goods)

Cluster/Variable	Containers	Supporting vessels
1	1.23	0.91
2	1	29.33
3	0	95.24

Source: own work.

Analysing the performance of the clusters, we can see that the ports from the first cluster seem to have moderate container activity and a lesser presence of supporting vessels. Their performance may be more balanced between container handling and supporting services. The second clusters perform differently. They have container activity, but are heavily involved in supporting services, possibly related to logistics, shipping, or offshore operations. The third cluster has a unique profile with no container activity, but a strong presence of supporting vessels. Their performance may be specialised in providing support and services to the maritime industry.

In summary, the first cluster and the second cluster have some similarities in container activity but differ significantly in supporting vessel presence, potentially indicating different areas of specialisation. The third cluster stands out with its unique focus on supporting vessels without container activity. The performance of each cluster would depend on their specific maritime activities and industry focus.

4.4 Maritime passenger transport

The cluster of maritime passenger transport has the distribution as it follows: the first clusters contain 8 ports, the second cluster 25 ports, and the third cluster 3 ports (Figure 5).

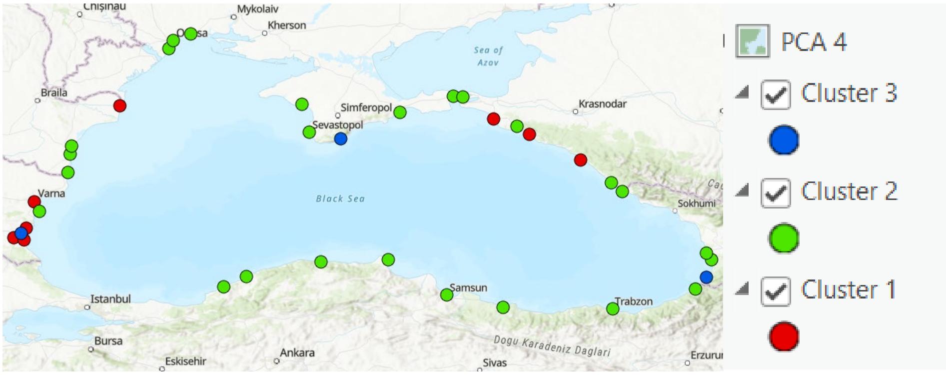

Figure 5. Clusters distribution of maritime passenger transport
Source: own work using ArcGIS Pro.

The first cluster is made by 8 ports: Sulina (Romania), Tuapse, Gelendzhik, Anapa (Russia), Varna, Burgas, Sozopol, and Nessebar (Bulgaria).

In the second cluster, there are 25 ports: Constanța, Mangalia, Midia (Romania), Yevpatoriya, Sevastopol, Chornomorsk, Kerch, Feodosiya, Odessa (Ukraine), Yuzhny, Adler, Kavkaz, Sochi, Novorossiysk (Russia), Fatsa, Samsun, Inebolu, Hopa, Bartin, Sinop, Zonguldak, Trabzon (Turkey), Balchik (Bulgaria), Supsa and Poti (Georgia).

In the third cluster, there are 3 ports: Yalta (Ukraine), Pomorie (Bulgaria), and Batumi (Georgia)

The first cluster represents the ports which have notable focus on passenger transport, similar with the third cluster they have relatively higher mean values for passenger transport boats compared to second cluster, indicating a stronger presence of passenger boats in these ports.

The second cluster has a significantly lower mean value for passenger transport boats compared to the other clusters. This suggests that these ports have fewer passenger boats anchored.

Table 7. The centres of cluster (maritime passenger transport)

Cluster/Variable	Passenger
1	18.74
2	1.31
3	48.27

Source: own work.

Analysing the performance of the clusters, we can see that the ports from the first and third cluster appear to perform well in terms of passenger transport, as indicated by their higher mean values for passenger boats. These ports may have a stronger tourism or passenger transport industry. On the other side, the ports from the second port may have a lower emphasis on passenger transport and may perform differently, possibly focusing on other maritime activities (Table 7).

In summary, the first cluster and the third cluster are characterised by a strong presence of passenger transport boats, suggesting a focus on passenger-related activities. In the second cluster, the ports have fewer passenger boats, indicating a different performance focus, possibly involving other aspects of maritime commerce or trade.

4.5 Maritime shipment

The first cluster is made up of 6 ports: Yuzhny, Kavkaz (Russia), Zonguldak, Feodosiya (Turkey), Odessa (Ukraine), and Poti (Georgia).

In the second cluster, there are 4 ports: Fatsa, Hopa, Bartin, and Trabzon (Turkey).

In the third cluster, there are 26 ports: Constanţa, Sulina, Mangalia, Midia (Romania), Yevpatoriya, Sevastopol, Chornomorsk, Kerch, Yalta (Ukraine), Adler, Tuapse, Sochi, Gelendzhik, Novorossiysk, Anapa (Russia), Samsun, Inebolu, Sinop (Turkey), Varna, Balchik, Pomorie, Burgas, Sozopol, Nessebar (Bulgaria), Supsa and Batumi (Georgia) (Figure 6).

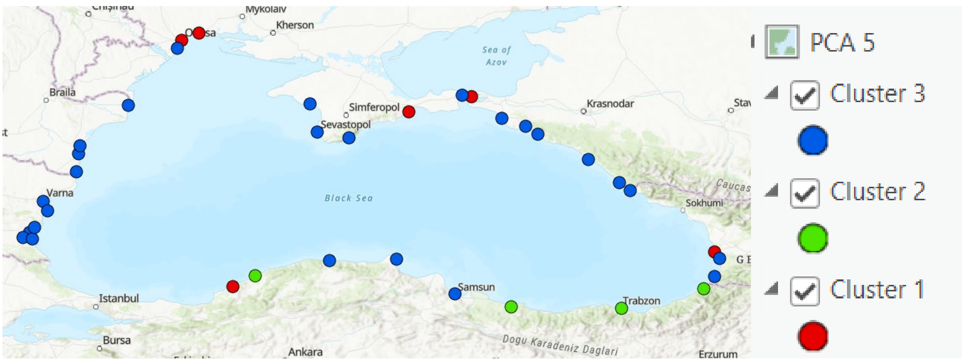

Figure 6. Clusters distribution of maritime shipment

Source: own work using ArcGIS Pro.

The first cluster and the third cluster have relatively higher mean values for "Other Markets," indicating a stronger presence of vessels operating in markets other than dry breakbulk in these ports. These clusters have a relatively higher mean value for "Other Markets" but differ in terms of their mean value for "Dry Breakbulk". The first cluster has a moderate presence of dry breakbulk, while Cluster 3 has a lower presence (Table 8).

The ports in the second cluster have a significantly higher mean value for "Dry Breakbulk," suggesting a strong focus on handling dry breakbulk cargo. This cluster has also a notably higher mean value for "Dry Breakbulk" compared to the cluster number 1 and 3. This indicates that the ports may be involved in heavy industry or trade in this category.

Analysing the performance of the clusters, we can see that the ports from the second cluster stand out as specialising in handling dry breakbulk cargo. On the other hand, the first cluster and the third cluster have a greater emphasis on other markets, but differ in their handling of dry breakbulk. Performance in these clusters may vary based on their specialisation and diversification in maritime activities.

Table 8. The centres of cluster (maritime shipment)

Cluster/Variable	Dry Breakbulk	Other Markets
1	9.7	63.66
2	80.77	13.46
3	6.59	9.18

Source: own work.

In summary, the second cluster stands out as specialising in handling dry breakbulk cargo. The first cluster and the third cluster have a greater emphasis on other markets but differ in their handling of dry breakbulk. Performance in these clusters may vary based on their specialisation and diversification in maritime activities.

4.6 Roll-on/Roll-off

The first cluster is made up of 3 ports: Tuapse (Russia), Samsun, and Zonguldak (Turkey).

In the second cluster, there are 3 ports: Sulina, Mangalia, and Midia (Romania).

In the third cluster, there are 30 ports: Constanța (Romania), Yevpatoriya, Sevastopol, Chornomorsk, Kerch, Feodosiya, Odessa, Yalta (Ukraine), Yuzhny, Adler, Kavkaz, Sochi, Gelendzhik, Novorossiysk, Anapa (Russia), Fatsa, Inebolu, Hopa, Bartin, Sinop, Trabzon (Turkey), Varna, Balchik, Pomorie, Burgas, Sozopol, Nessebar (Bulgaria), Supsa, Poti, and Batumi (Georgia) (Figure 7).

Figure 7. Clusters distribution of Roll-on/Roll-off
Source: own work using ArcGIS Pro.

The ports from the first cluster have a moderate presence of LPG carriers and a notably higher presence of RO-RO vessels. Similar to the first cluster, is the third cluster these having higher mean values for RO-RO vessels compared to second cluster, indicating a stronger presence of Roll-On/Roll-Off vessels in these ports. On the other hand, the third port has a minimal presence of LPG carriers and a moderate presence of RO-RO vessels. The first cluster has a stronger presence of both vessel types compared to the third cluster.

The second cluster has a significantly higher mean value for LPG carriers but no presence of RO-RO vessels, distinguishing them from the other clusters.

Analysing the performance of the clusters, we can see that the ports from the first cluster perform well in terms of the presence of RO-RO vessels, which could indicate their importance in logistics and vehicle transportation. In the second cluster the ports are specialise in LPG carriers but do not have RO-RO vessels, suggesting a different focus in their maritime activities. In the third cluster, the ports have minimal presence of LPG carriers and RO-RO vessels, indicating a more balanced maritime activity profile without a strong emphasis on these specific vessel types (Table 9).

Table 9. The centres of cluster (Roll-on-Roll-off)

Cluster/Variable	LPG Carriers	RO-RO
1	0.44	5.11
2	2.64	0
3	0.061	0.14

Source: own work.

In summary, the first cluster excels in RO-RO vessel presence, the second cluster is specialised in LPG carriers, and the third cluster maintains a balanced maritime activity profile with a moderate presence of both vessel types. Performance may vary based on the specialisation and diversity of maritime activities in these clusters.

Most of the Black Sea ports, regardless of the country of origin, are characterised by an industrial profile, mainly economic operators operating in these ports are carriers of fossil fuels. However, at Black Sea level there are a number of ports that are characterised by a high volume of tourists and fishing activity, such as: Russia (Sochi, Gelendzhik, and Novorossiysk), Bulgaria (Sozopol, Balchik, Nessebar). Ports such as Constanta (Romania), Varna (Bulgaria), Odessa (Ukraine), Samsun (Turkey), or Batumi (Georgia) are ports with a role, mainly industrial, but they also present a relatively high flow of maritime traffic for tourism purposes. At the opposite end, ports with just an industrial character turn out to be Mangalia, Midia, Sulina (Romania), Yalta, Sevastopol (Ukraine), Kavkaz, Adler, Anapa (Russia), Samsun, Trabzon (Turkey). Another interesting aspect is represented by the association of ports in clusters on each phenomenon. Thus, with few exceptions, several patterns of association have been identified. For example, ports from Romania and Bulgaria, especially Constanta and Varna, show a similar pattern of economic competitiveness, the cause of this effect being very likely the cooperation relationship between the two neighbouring countries, but also their integration into the European Union. On the other hand, Turkish ports are often associated with those of Russia, which leads to the conclusion that through the relations and trade carried out by the two countries at the Black Sea level, they have developed their transport infrastructure in an almost similar way. The particular cases are represented by ports in Ukraine and Georgia. These ports are usually associated with those in Russia, a sign that the economic competitiveness model developed by the Kremlin is still felt, but, at the same time, in some cases, the European model makes its presence felt, and ports from these countries (Ukraine and Georgia) associate with ports from the European Union (Romania and Bulgaria).

The ports of Russia (Sochi, Gelendzhik, and Novorossiysk) are characterised by a high volume of passengers, as a result, mainly, of the tourist character of these ports.

5. Conclusions and Future Work

Mainly, the ports in Romania and Bulgaria are characterised by an important flow of passengers, as a result of the tourist activity, but also as a result of the industrial character, at least in the case of the ports of Constanța and Varna. Russian ports (Sochi, Gelendzhik, and Novorossiysk) have the largest transport flow in the Black Sea, mainly generated by the war in Ukraine. Contrastingly, these ports also register the highest share of vessels used for recreational purposes.

Most ports opening to the Black Sea are characterised by wet bulk transport, LPG carriers, but also by a reduced activity of fishing and Dry Breakbulk transport, which leads to the idea of shaping an industrial profile of these ports. However, as an exception to the previous conclusion, eight ports (Yevpatoriya, Kerch, Balchik, Sevastopol, Pomorie, Sozopol, Nessebar and Supsa) present a more touristic and recreational activity. Even in this context, these eight ports show the lowest flow of passengers among the ports opening to the Black Sea.

In conclusion, it can be stated that at the level of the Black Sea, the ports with an outlet to it are transited by vessels transporting, mainly, fuels, such as: natural gas, oil, etc. This fact is primarily due to the deposits rich in fuel, which exist in the Black Sea plateau. On the other hand, there are a number of ports that play a more touristic role, especially ports in Bulgaria, such as: Balchik, Sozopol, or Nessebar.

The limited number of variables and the periodicity of the data are two important limitations of the research that can influence the characterisation of the pattern of ports opening to the Black Sea.

Given the heterogeneity of the countries from which these ports come, in the future, a development direction of this study can be the use of an exploratory factor analysis to identify the role of national policies at the maritime transport level.

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