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# Assessment of freight traffic flows and harmful emissions in euro-mediterranean context: scenario analyses based on a gravity model

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## Abstract

Maritime transport contributes significantly to environmental pollution. The Mediterranean Sea Area is particularly affected by marine emissions from particulate matter, black carbon, nitrogen oxides and sulphur oxides. In addition to international and crossing traffic, the Mediterranean Sea is affected by the freight flows moved between its shores (in the North–South direction and vice versa), but also by transverse freight flows (East–West); these are freights transported through Short Sea Shipping. The Mediterranean Sea is the area where there is the highest concentration of short sea shipping in the EU-27. There are different types of Short Sea transport: container and bulk handling, general cargo ships and Ro-Ro transport. In such scenario, the analysis of trade flows as well as their spatial and geographical distribution, becomes fundamental. The paper proposes a gravity model for estimating trade flows, considering 18 countries boarding the Euro-Mediterranean Sea, in 2019. The proposed gravity model assumes that one of the main factors affecting trade is the economic dimension of a country which is directly related to the volume of imports and exports. In the paper, after a literature review on the gravity models, the illustration of the different phases investigation and construction of the database (specification, calibration and validation) to the definition and implementation of the proposed model is proposed. Scenario analyses are therefore proposed for assessing the environmental impacts generated by maritime transport in the Mediterranean basin as the freight flows vary. The analyses are carried out using a simulation approach which, starting from hypotheses on the economic and social development trends of the countries of the southern shore, made it possible to evaluate the variations in terms of freight flows and environmental impacts in terms of pollution.

**Keywords:** Maritime freight traffic, Technologies, Environmental pollution, Mediterranean sea area, Simulation approach, Gravity model, Trade flows, Economic and social development

## Introduction

The Mediterranean Sea area, place of the most of European shipping, is strongly affected by particulate matter emissions, black carbon, nitrogen oxides and sulphur oxides. More than 600 freight yards are in the Euro-Mediterranean area (more than 20 located in the European Union) and 500,000 employees are in the maritime transport sector, generating an added value (GVA) equal to 27 billion of Euro. The Mediterranean fleet is made up of approximately 8,000 ships, representing 210 million gross tonnages (Randone et al. 2019).

In addition to international and crossing traffic (Suez Canal-Strait of Gibraltar), the Mediterranean Sea is affected by the freight flows moving among its shores (in the North–South direction and vice versa), but also by cross freight flows (direction East–West and vice versa); these are typically Short Sea Shipping flows.

There are different types of Short Sea transport as containers and bulk handling, general cargo, Ro-Ro ships, etc. An important role is played by the traffic of liquid and solid bulk, with a share equal to approximately 58% of the total goods moved in the Short Sea segment.

In the last 20 years, the Ro-Ro traffic in the Mediterranean has exceeded the threshold of 4 million units, with a growth of 255%, so that, transport by ferry has reached the containers transport. In 2017, 70,000 Ro-Ro vehicles were detected in the Mediterranean, an increase of 7.4% compared to 2012 (SRM 2018). Eurostat data show that in the EuroMed area Ro-Ro traffic in 2018 handled about 81 million tons of goods (about 14% of the total).

22 countries bordering the Mediterranean Sea have begun negotiations for the establishment of a low-emission zone (MED ECA), such as the one in force in the Baltic Sea, the North Sea and the English Channel for the protection of the whole eco-system.

In this scenario, the analysis of trade flows and their spatial and geographical distribution becomes fundamental in order to evaluate the current and predict future traffic, and to estimate the emissions generated by maritime transport in the Euro-Mediterranean area.

The paper proposes a gravity model for estimating the trade flows within the Mediterranean basin with specific reference to maritime transport. The gravity model assumes that one of the main factors affecting trade is the economic dimension of a country which is directly related to the volume of imports and exports: economically “stronger” countries on the one hand produce more goods and services and therefore can sell more on the foreign market, on the other hand they generate more income and therefore their residents are able to import more.

The gravity model is widely used in the literature for the estimation of freight flows with reference to limited geographical areas. The work proposes a calibration of the model with reference to a wide area such as the Euro-Mediterranean one, which has never been considered until now.

The model wants to be more agile, faster and more friendly than the literature models that consider a set (often numerous) of proxy variables with the aim of explicitly taking into account environmental conditions (political situation, conflict, social status, trade agreements) that could affect the freight flow among states.

After a brief state of the art about the gravity models applied in the literature, the different phases of the model construction will be introduced: survey and building of the database, specification, calibration and validation.

Therefore, some scenario analysis will be proposed for the assessment of the environmental impacts generated by maritime transport in the Mediterranean basin according to the variation of the freight flows. The analysis has been carried out through a simulation approach; some hypotheses have been made on the economic and social development trends of the countries of the southern shore, to evaluate the variations in terms of freight flows and environmental pollution.

Future scenarios include an option based on the use of “green” ships with clean technologies (zero-carbon fuels) through a mix of solutions: LNG, electrification, liquid hydrogen/ammonia, hybrid engines.

### Literature review

The availability of a good, in a given area, for the final consumption is made possible thanks to its production in another area: the resulting movement between the production and the consumption area can therefore be represented by a matrix of demand for goods. In the specialized literature, the simulation of demand exchanges is made according to two different approaches. In the first case, the export and import demand are assessed separately using a generation-distribution model and an attraction-acquisition model respectively. In the second case, the joint definition of the import/export demand is carried out using a gravity model.

In world trade theories, the universal gravity model gives a positive connection among the international trade flows and the country size, measured by its GDP and the distance between the import country and the export country. The economic dimension is important in the model because larger countries generate more income from the sale of goods and services, therefore their residents are able to import more. The distance, instead, affects the ability to create contacts and facilitate communications, which affect the trade.

This topic has consolidated application in transport engineering and economic geography, with numerous contributions summarizing the state of the art (Suárez et al. 2021; Kohl 2014; Kepaptsoglou et al. 2009; Carrere 2006; Egger 2002; Porojan 2001; Bergstrand 1985).

The model was firstly formulated by the economist *Tinbergen* in 1962 (after reviewed and consolidated by *Pulliainen* in 1963 and *Bergstrand* in 1985), and it is based on the idea that the geographical proximity facilitates trade for several reasons, from low transport costs to institutional and language similarities among states.

Other authors have used the gravity model to evaluate the impact of some economic policy choices, both in its basic and extended version to include variables of different nature. Such models are sometimes complex as they consider a set (often numerous) of proxy variables with the aim of explicitly take account surrounding conditions (political situation, conflict, social state, specific commercial agreements) that could influence the freight flow among states.

Table 1 shows some literature studies related to the estimation of trade flows by a gravity model. The reference areas and temporal horizon of data are specified.

**Table 1** Gravity models for freight flows estimation

Authors, year	Study description	Study area	Data period
Kalirajan (1999)	Stochastic gravity model to estimate the potential trade flows between countries varying model coefficients	Australia, its trading partners in the Indian Ocean	
Rose et al. (2000)	Gravity model to assess the separate effects of exchange rate volatility and currency unions on international trade	186 countries	1970–1990
Egger (2002)	Comparison among several models to demonstrate, that the choice of the econometric set-up is of great relevance for the calculation of bilateral trade potentials	OECD countries, 10 Central and Eastern European countries	1986–1997
Egger (2004)	Three different methods to obtain a global regional trade blocking effect with panel data	OECD economies to 47 partner countries	1986–1997
Kang and Fratianni (2006)	Stochastic frontier estimation to quantify trade efficiency as the distance between trade flows and the maximum possible trade flows predicted	177 countries	1975, 1980, 1985, 1990, 1995, 1999
Kandogan (2007)	Different gravity models to compare and evaluate the specifications proposed in the literature and to examine the role of blocs in trade across different models	99 countries	1992–1999
Chen et al. (2007)	Gravity model, considering trade indicators, to analyze the degree of trade concentration. The variables have been into 3 groups in relation to market size; distance and regional composition	10 countries in the East Asia	1990–2005
Martínez et al. (2009)	Static and dynamic gravity model to evaluate the effects of preferential agreements on trade, using a panel data technique	15 countries of EU, NAFTA, CARICOM, MCCA, MAGHREB	1980–1999
Leusin and de Azevedo (2009)	Gravity model, using cross-sectional to analyze the border effect for goods	26 brazilian states + the Federal District, 40 other countries	1999
Madhusoodanan (2010)	Augmented gravity model to examine the impact of a set of macroeconomic and other policy factors on trade flows	SAARC region	
Blanes and Milgram (2010)	Gravity model, using data disaggregated by region and industries, to analyze the impact of the free trade area considering tariffs at the industry level	EU and Morocco on the exports of the Spanish regions	1999–2002
García et al. (2013)	Augmented gravity model to examine annual bilateral exchanges considering variables of the international trade volume and direction	75 Mercosur countries	1980–2008

**Table 1** (continued)

Authors, year	Study description	Study area	Data period
Vijil (2014)	Gravity model to show the complementarities between the aid for trade and regional economic integration	185 countries	1995–2005
Dragutinović-Mitrović and Bjelić (2015)	Gravity model to investigate the role of different trade regimes in determining the bilateral trade, using panel data	Western Balkan countries and the enlarged EU	2001–2010
Bermeo and Oh (2016)	Gravity model to examine Peru’s trade patterns by analyzing the country’s bilateral trade flows. The empirical results using the Tobit model for the whole dataset are consistent with the general prediction of the gravity model	186 countries	1990–2011
Bary and Setyodewanti (2016)	Gravity model, using panel-bilateral manufacturing trade, and comparing the trade creation and trade diversion effects across countries in relation to the implementation of a Regional Trade Agreement	Southeast Asia	1990–2012
Ahcar and Siroën (2017)	Gravity model to test the effect of depth on trade, considering additive indicators as factor variables and use multiple correspondence analysis, to obtain distilled indicators of deep integration	153 countries	1980–2012
Suárez et al. (2021)	Gravity model with two distance variables which are built as modernity factors of culture and productive and institutional apparatus	21 regions of Colombia	1995–2015

**Gravity models for the freight transport. The methodology**

The proposed methodology follows the Timbergen’s Gravity Model:

$$F_{ij} = G \frac{M_i^{\beta_1} M_j^{\beta_2}}{D_{ij}^{\beta_3}}$$

where  $F_{ij}$  is the export flow from country  $i$  to country  $j$ ;  $G$  is a constant;  $M_i$  and  $M_j$  represent the economic mass of the exporting and importing countries respectively (generally represented by GDP and, sometimes, by the population or by both variables);  $D_{ij}$  is the distance between the countries;  $\beta_k$  are the model parameters.

The logarithmic transformation of the previous equation translates in the following linear function:

$$\ln F_{ij} = \alpha + \beta_1 \ln M_i + \beta_2 \ln M_j + \beta_3 \ln D_{ij}$$

where  $\alpha$  is the intercept and the sum of  $\beta_n$  is the slop of the straight line.

Several hypotheses have been formulated regarding the determination of the optimal distance measure, including the geographical distance among the countries “centers of gravity” or among the country’s capitals. Other proposals consist in measuring the distances directly through transport costs. Other variables can be combined with the distance in determining the impedance factors, such as the technological distance, understood as the difference in the technological level between the two countries.

According to *Head (2000)*,  $\beta_1$  and  $\beta_2$  should be equal to one but, usually, in the several empirical works the values are between 0.7 and 1.1. The comparison between  $\beta_1$  and  $\beta_2$  can be used for some economic interpretations: according to some authors (*Feenstra et al. 2001*) if  $\beta_1 \geq \beta_2$ , there is the so-called *home market effect* which occurs when the output supply of a country grows more than the domestic demand, thus stimulating export flows.  $\beta_3$  should be negative ( $\beta_3 < 0$ ) because the distance is used as a “proxy” variable that is as an approximation of the transport costs and other factors such as the perishable nature of the goods, the communication and transaction costs and the “cultural distance”, that constitute an obstacle to international trade. In fact, in *Head’s study*, the average value of  $\beta_3$  is equal to -0.94: this can be interpreted in the sense that a doubling of the distance would have the effect of halving trade between the two countries (*Head 2000*).

**Gravity model for freight flows in the euro-mediterranean context**

A gravity model for the estimation of the freight flows in the Mediterranean Sea has been specified and calibrated. It is simple to be easily applied to a large study area but, at the same time, it retains some relevant modelling characteristics such as to allow a not excessively simplified representation of reality. The gravity model appears suitable for modelling demand flows for the Euro-Mediterranean area. The specific reference is to maritime transport and, in particular, dry bulk, liquid bulk, containers, Ro-Ro and other cargo transport.

In the phase of model calibration, the import/export flows in the Euro-Mediterranean area among 18 countries (8 on the northern shore and 10 on the southern shore) have been considered (Fig. 1).



**Fig. 1** Context of model calibration

The information and data useful for specifying and calibrating the model have been obtained through a complex procedure that required the acquisition, processing and aggregation of data from several online databases. In particular, World Bank Group, World Trade Organization and EUROSTAT database have been consulted. On the basis of the information obtained, the commercial profiles of the States bordering the Mediterranean Sea have been carried out, indicating, for each of them, the GDP, the population, the trade flows in terms of exports and imports moved by 5 different types of maritime transport: liquid bulk, dry bulk, containers, Ro-Ro and general cargo. The data have been systematized and organized in a synthetic, modular, potentially and periodically updatable database.

The freight exchanges in the area have been evaluated through the composition of appropriate Origin/Destination matrices. Table 2 shows the O/D matrix of export flows of container transport in 2019.

The reference model is a gravity model in its logarithmic shape in which the dependent variable ( $F_{ij}$ ) is the logarithm of the export trade flow between country  $i$  and country  $j$ ; the three independent variables are represented by the logarithms of the economic mass of the origin country  $i$  ( $M_i$ ) and of the destination country  $j$  ( $M_j$ ) and by the logarithm of the distance between them ( $D_{ij}$ ):

$$\ln F_{ij} = \beta_1 \ln M_i + \beta_2 \ln M_j + \beta_3 \ln D_{ij}$$

The economic mass has been assessed by referring to the GDP of the single country; the distance has been evaluated as the intermodal temporal distance, that is, the time necessary to ensure the connection between the exporting country and the importing one by intermodal road-sea transport (Fig. 2).

The distance has been assessed by taking as reference the main container port of each country; the origin and destination of the commercial flow have been in barycentric position of each country area, considering that, in the transport sector the barycentre is chosen in relation to the activities and the population density of the area. In African countries, the centroid is located towards the Mediterranean coast.

The temporal distance  $T_{ij}$  has been defined as:

$$T_{ij} = T_{io} + T_{od} + T_{dj}$$

where

- $T_{io}$ : time to reach the port  $o$  of the exporting country by road starting from the barycentre  $i$  of the same country;
- $T_{od}$ : time for the maritime connection between the port  $o$  of the exporting country and that one  $d$  of the importing country, including manoeuvre and hoteling times;
- $T_{dj}$ : time to reach the final destination (that is the centre of activity  $j$ ) starting from the port  $d$  by road mode.

The calculation of the travel times on the road has been carried out by an aggregate model:

$$T_{io} = L_i/v_i$$

**Table 2** O/D Matrix-export flows of container transport in 2019 (1,000 tons)

GR	ES	FR	HR	IT	CY	MT	SI	AL	TR	DZ	LY	MR	TN	EG	IL	LB	SY	TOT
GR	0	436	58	381	2046	884	331	232	238	1039	412	366	5	1234	508	265	538	8977
ES	930	0	284	49	2371	95	310	32	69	2662	1378	255	261	955	1082	519	118	11,749
FR	72	124	0	0	14	5	62	0	1	242	620	21	37	103	77	48	5	1513
HR	259	0	0	0	132	0	114	3	0	0	0	0	0	112	0	0	0	620
IT	1811	1943	2851	111	0	111	1938	490	186	1783	890	578	1011	1672	745	253	18	16,720
CY	86	2	0	0	38	0	0	2	0	0	0	0	0	0	0	63	0	191
MT	1	8	0	0	3	0	0	0	4	9	88	0	1	1	0	0	0	115
SI	650	0	0	3	95	34	327	0	0	173	17	0	0	707	227	40	0	2273
AL	183	10	0	11	103	0	1	0	0	0	0	0	0	0	0	0	0	191
TR	1801	2164	366	0	3797	0	1745	145	7	0	998	1220	637	1859	3567	1227	150	20,003
DZ	8	449	155	0	120	4	0	0	66	0	0	0	0	0	0	0	0	802
LY	8	3	1	0	18	0	0	0	76	0	0	0	0	0	0	0	0	106
MR	44	195	15	0	185	1	0	0	172	0	0	0	0	0	0	0	0	612
TN	4	205	55	0	92	1	4	0	52	0	0	0	0	0	0	0	0	413
EG	456	1024	95	67	1739	0	11	375	0	1974	0	0	0	0	0	0	0	5741
IL	257	789	183	0	233	0	1	222	0	2823	0	0	0	0	0	0	0	4508
LB	42	144	2	0	867	7	4	2	0	1738	0	0	0	0	0	0	0	2806
SY	32	12	1	0	1	1	0	0	111	0	0	0	0	0	0	0	0	158
TOT	6644	7508	4066	622	11,854	1143	4848	1503	501	12,915	4324	2528	1951	6643	6206	2415	829	77,308

GR-Greece; ES-Spain; FR-France; HR-Croatia; IT-Italy; CY-Cyprus; MT-Malta; SI-Slovenia; AL-Albania; TR-Turkey; DZ-Algeria; LY-Lybia; MR-Morocco; TN-Tunisia; EG-Egypt; IL-Israel; LB-Lebanon; SY-Syria





**Fig. 2** Scheme for the calculation of the intermodal time distance

**Table 3** Speed and times at node for different types of ships. *Source* Elaboration on Whall et al. (2002)

Ship	Av. Navigation Speed (km/h)	Av. manoeuvre time (h)	Av. hoteling Time (h)
Liquid bulk	26.0	1.5	38.0
Dry bulk	26.5	1.0	52.0
Container	35.7	1.0	14.0
Ro-Ro	28.6	1.0	15.0
Other Cargo	20.0	1.0	27.0

where  $L_i$  is the distance by road travelled in the country  $i$  and  $v_i$  is the commercial speed varying in relation to the specific country.

The travel time by sea ( $T_{od}$ ) has been assessed considering the navigation time and the time lost at the port for manoeuvring, loading/unloading and retooling (hoteling time).

Table 3 shows the average speeds and the average times at node for different types of ships.

Different time distances matrices have been obtained in relation to the type of the maritime service. By way of example, Table 4 shows the matrix of the time distances for container transport.

The individuation of the model variables has been carried out on the basis of statistical considerations through the analysis of regression matrices, scatter plots describing all the possible correlations between pairs of variables.

The matrices construction has highlighted the type and degree of relationship existing between the response variable, that is the flow in export from  $i$  to  $j$ , and the explanatory variables of the problem; in addition, the matrices made it possible to assess the degree of relationship between the independent variables examined, allowing for checks on their independence.

**Table 4** O/D Matrix-time distances for container transport (h)

	GR	ES	FR	HR	IT	CY	MT	SI	AL	TR	DZ	LY	MR	TN	EG	IL	LB	SY
GR	0	75	71	57	54	43	43	59	39	120	71	49	87	54	42	49	49	48
ES	75	0	26	81	45	96	51	83	64	84	30	55	39	41	92	102	102	102
FR	71	26	0	76	40	92	49	78	59	79	37	54	48	40	88	98	98	98
HR	57	81	76	0	22	78	52	21	36	65	78	61	93	61	75	84	84	84
IT	54	45	40	22	0	75	33	22	33	62	46	42	61	32	67	77	81	81
CY	43	96	92	78	75	0	63	80	60	42	92	68	107	74	30	23	23	23
MT	43	51	49	52	33	63	0	54	35	51	46	26	61	28	58	69	69	69
SI	59	83	78	21	22	80	54	0	38	67	80	63	95	63	77	86	86	86
AL	39	64	59	36	33	60	35	38	0	47	61	44	76	44	57	65	66	65
TR	120	84	79	65	62	42	51	67	47	0	79	57	95	62	43	48	48	47
DZ	71	30	37	78	46	92	46	80	61	79	0	50	32	36	87	98	98	98
LY	49	55	54	61	42	68	26	63	44	57	50	0	66	33	60	73	74	75
MR	87	39	48	93	61	107	61	95	76	95	32	66	0	51	103	113	113	113
TN	54	41	40	61	32	74	28	63	44	62	36	33	51	0	70	80	80	80
EG	42	92	88	75	67	30	58	77	57	43	87	60	103	70	0	31	33	37
IL	49	102	98	84	77	23	69	86	65	48	98	73	113	80	31	0	20	25
LB	49	102	98	84	81	23	69	86	66	48	98	74	113	80	33	20	0	21
SY	48	102	98	84	81	23	69	86	65	47	98	75	113	80	37	25	21	0

GR-Greece; ES-Spain; FR-France; HR-Croatia; IT-Italy; CY-Cyprus; MT-Malta; SI-Slovenia; AL-Albania; TR-Turkey; DZ-Algeria; LY-Lybia; MR-Morocco; TN-Tunisia; EG-Egypt; IL-Israel; LB-Lebanon; SY-Syria

**Table 5** Calibration results

Service type	Parameters		
	$\beta_1$	$\beta_2$	$\beta_3$
Liquid bulk	0.418	0.369	- 1.746
Dry bulk	0.287	0.294	- 0.757
Container	0.320	0.189	- 0.299
Ro-Ro	0.280	0.359	- 1.288
General Cargo	0.157	0.101	- 0.522

The model calibration, for the different types of maritime service, has been carried out with reference to a multiple linear regression model and using the least squares method for estimating the unknown parameters. The calibration results are shown in Table 5.

For goods moved by liquid bulk, container and general cargo transports,  $\beta_1$  is greater than  $\beta_2$  for which there is monopolistic competition that produces the so-called home-market effect. Monopolistic competition is a market structure that combines elements of monopoly and competitive markets. Country  $i$  (origin) is configured as a net exporter, i.e., the commercial supply produced generally exceeds domestic demand with an accentuation of export flows, therefore the exports of country  $i$  are more sensitive to its own income than to that of the destination country.

For goods moved by dry bulk and Ro-Ro transport, this relation is reversed ( $\beta_1 < \beta_2$ ) and the exports of country  $i$  (origin) are more influenced by the income of the destination country  $j$ .

**Table 6** Regression statistics

Service type	Multiple $R$	$R^2$	Adjusted $R^2$	Standard error	Observ. Nb
Liquid bulk	0.993	0.986	0.977	1.528	115
Dry bulk	0.995	0.990	0.981	1.213	115
Container	0.994	0.987	0.979	1.446	127
Ro-Ro	0.991	0.983	0.965	1.530	60
General Cargo	0.960	0.921	0.906	1.316	77

**Table 7** Analysis of variance-Statistics  $F$ 

Service type	$F$	Significance $F$
Liquid bulk	2,620.96	7.9E-103
Dry bulk	3,575.81	3.2E-110
Container	3,168.16	3.1E-116
Ro-Ro	1,101.11	9.8E-50
Other Cargo	288.59	2.1E-40

The intermodal distance weighs in a decisive way in the development of commercial relations between the countries considered; in fact,  $\beta_3$  assumes values higher than or close to one (except in container transport) demonstrating that the doubling of the distance corresponds to a halving of export trade flows between the countries.

For the validation of the models, in the first instance, the evaluation of the determination coefficient  $R^2$  and of the multiple coefficient of determination  $R$  have been carried out. Table 6 shows the validation results.

The linear regression models proposed for the different maritime transport provide multiple  $R$  values close to 1, demonstrating the strong linear relation between the observed values and the corresponding estimated.

Even the values of  $R^2$  are close to one, it is therefore possible to state that the variability of the export flow is satisfactorily explained by the explanatory variables GDP exporting country, GDP importing country and intermodal temporal distance through the regression model with a good linear correlation.

There are also low standard errors ranging from 1.2 to 1.5.

After evaluating the “goodness of fit” of the calibrated models, through the  $F$  test (Table 7), the presence of a significant relation between the dependent variable and the set of explanatory variables considered has been verified.

The significance value of  $F$  is well below 5% therefore the results obtained are statistically significant (i.e., reliable), so the model used is good.

Despite the goodness of the model, the analysis and comparison between the estimated and real values led to consider a correction factor  $G$  in the transition from logarithmic to exponential notation (Table 8).

**Table 8** Values of gravity model parameters

Service type	$\beta_1$	$\beta_2$	$\beta_3$	G
Liquid bulk	0.418	0.369	- 1.746	1.5
Dry bulk	0.287	0.294	- 0.757	1.5
Container	0.320	0.189	- 0.299	1.4
Ro-Ro	0.280	0.359	- 1.288	0.9
General Cargo	0.157	0.101	- 0.522	1.3

**Table 9** Emission factor by ship type (g/KWh). *Source* Elaboration on Whall et al. (2002)

Ship type	$EF_p$			
	NO <sub>x</sub>	SO <sub>2</sub>	CO <sub>2</sub>	HC
Liquid bulk	14.9	11.7	689	0.5
Dry bulk	17.9	10.6	624	0.6
Container	17.5	10.7	631	0.6
Ro-Ro	15.6	11.2	659	0.5
General Cargo	14.0	11.5	678	0.5

**Emissions estimation from maritime shipping**

Maritime transport generates numerous impacts on the marine ecosystem due, for example, to the engines, the spillage of oils and other contaminating liquids into the water, the loss or discharge of solid materials, the emission of air pollutants. In the paper, attention is paid to emissions into the air (NO<sub>x</sub>; SO<sub>2</sub>; CO<sub>2</sub>; HC).

CO<sub>2</sub> contributes to global warming by trapping heat in the atmosphere and negatively affects marine ecosystems by increasing the acidity of sea water. Sulphur dioxide (SO<sub>x</sub>) emitted by the maritime sector contributes to acid rain, which has a negative impact on health. Nitrogen oxides (NO<sub>x</sub>) are gases that can cause acidification and eutrophication of water and soil; in fact, NO<sub>x</sub> emissions on the one hand increase the presence of nutrients in sea water leading to abnormal growth of algae, on the other hand they favour the formation of particulate matter and ground-level ozone.

The evaluation of the emissions generated by a pollutant  $p$  ( $E_p$ ) can be evaluated using the following expression:

$$E_p = EF_p \cdot T_{od} \cdot P_s \cdot N_{sy}$$

where  $EF_p$  is the emission factor of the pollutant  $p$  in g/KWh;  $T_{od}$  is the time of navigation by sea from the port  $o$  to the port  $d$ ;  $P_s$  is the engine power for the  $s$  ship type;  $N_{sy}$  is the number of  $s$  ships type offering the maritime transport service in year  $y$ .

Tables 9 and 10 give respectively the values of the emission factor pollutant and the average power values of the main engines by type of ship.

The time  $T_{od}$  can be evaluated as described previously.

The number of  $s$  ships type for the transport service  $s$  in year  $y$  can be evaluated as:

$$N_{sy} = F_{sy}/C_s$$

**Table 10** Average power values by ship type (KW). *Source* Trozzi (2010)

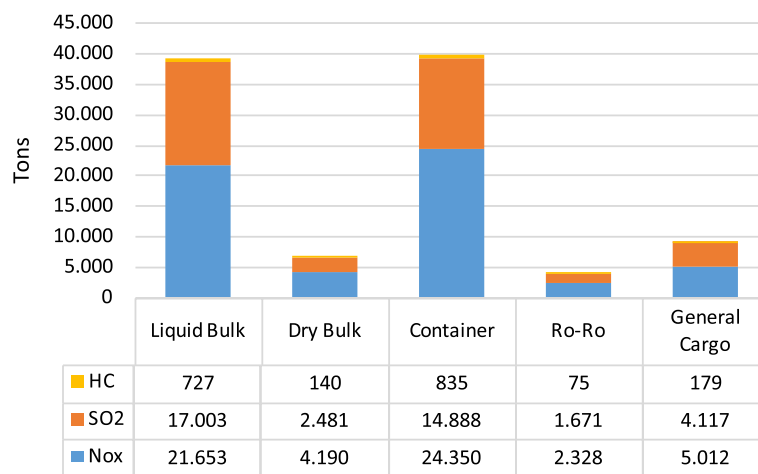
Ship type	Power of main engines
Liquid bulk	6543
Dry bulk	4397
Container	14,871
Ro-Ro	4194
General Cargo	2555

where  $F_{sy}$  is the flow of goods moved by the transport service  $s$  in year  $y$ ;  $C_s$  is the average capacity of the ships operating the maritime service  $s$ . This average capacity (Table 11) has been assessed with reference to a large database built by a detailed survey which included the monitoring of ships in the Mediterranean Sea and the detection of their characteristics.

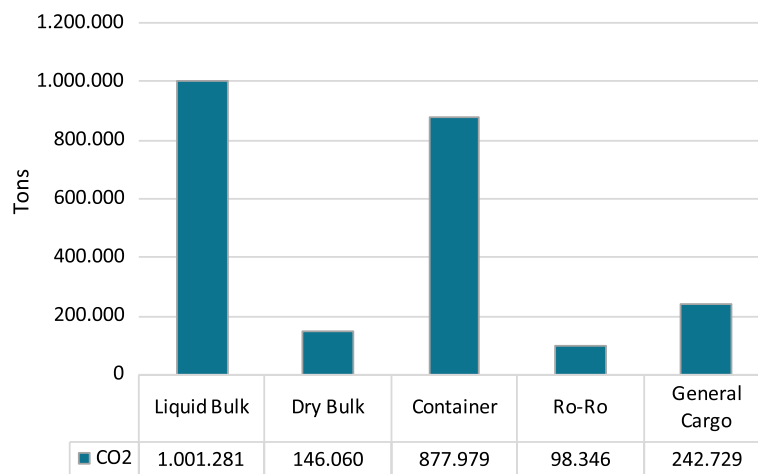
Using the model, the polluting emissions generated by intra-Mediterranean maritime transport have been evaluated, in 2019 (Figs. 3 and 4). Intra-Mediterranean maritime traffic flows generated the emission into the air of about 1,800,000 tons of pollutants of different types. About 96% of emissions concerns the production of  $CO_2$ , 2.35% the  $NO_x$ , 1.63%  $SO_2$  and 0.08% HC.

**Table 11** Average ship capacity by type

Ship	Measure Unit	$C_s$
Liquid bulk	DTW (ton)	43,490
Dry bulk	DTW (ton)	40,374
Container	TEUs	2027
Ro-Ro	DTW (ton)	29,387
General Cargo	DTW (ton)	7623



**Fig. 3** Emissions of HC,  $SO_2$  and  $NO_x$ . Maritime transport in 2019



**Fig. 4** Emissions of CO<sub>2</sub>. Maritime transport in 2019

### Case study and scenario analysis

The specified, calibrated and validated model has been used to analyze full-scale scenario assessments. The analysis has been carried out using a simulation approach (what if) and making some hypotheses on the economic and social development trends of the southern Mediterranean countries. The variations of the freight flows and environmental impacts in terms of pollution have evaluated.

Considering a temporal horizon of 40 years, three different scenarios have been envisaged:

- Scenario 0: current state;
- Scenario 1A: GDP increase of 20% for the countries on the Mediterranean southern shore;
- Scenario 1B: evolution of Scenario 1A with renewal of 20% of the maritime fleet using “green” ships with clean technologies (zero-carbon fuels) and a mix of solutions as: LNG, electrification, liquid hydrogen/ammonia, hybrid engines. The use of “green” ships would allow an average reduction of 40% of the emission factor of each kind of ships.

The time horizon of 40 years has been chosen in relation to the evolutionary dynamics of the market; some changes in the structure are expressed in a medium-long time horizon. The scenario hypotheses are from the direct experience of the authors and from the bibliometric analysis; in particular, many analysts point to a higher GDP growth trend for countries on the south eastern shore than for European countries. Cautiously, an annual growth of 0.5% has been assumed. Starting from the concept that an average life span of a fleet is around 50–60 years, a share of the vessels could be newly built, a 20% renovation is reasonable.

Finally, 40% reduction of ships emission has been defined in relation to some bibliographic studies that foresee a drastic reduction of emissions in relation to the technological innovation of ships engines.

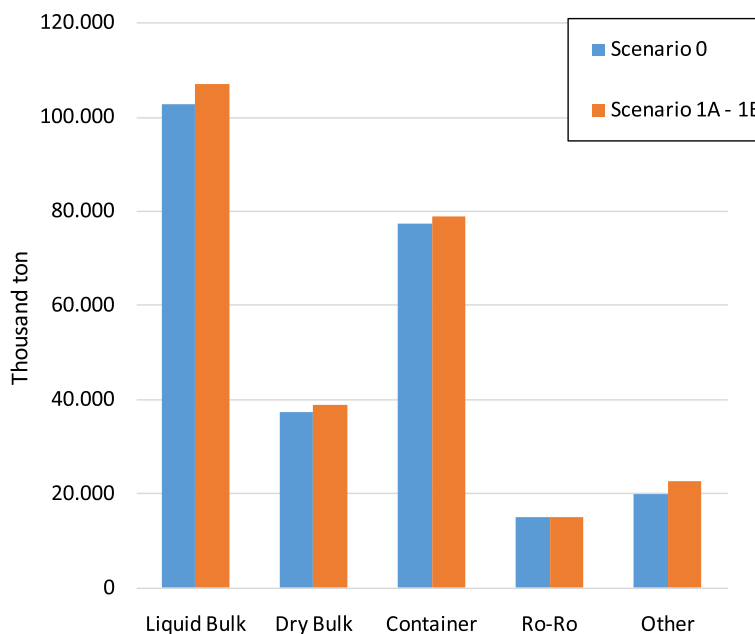
The 20% increase in GDP of the countries on the southern shore of the Mediterranean area generates an increase in goods flows different in relation to the maritime service considered (Fig. 5). For Liquid Bulk and Dry Bulk transport the increase in export flows is 4%, for container traffic it is about 2%, for General Cargo it is about 13%. Ro-Ro traffics show the lowest percentage increase, which is around 1%.

The increase in traffic flows determines a consequent increase in the number of ships moving in the Mediterranean basin in a year. In scenario 1A, a significant increase in polluting emissions emerges on average equal to 5% for Liquid Bulk Dry Bulk, Ro-Ro and Container services around 60% for General Cargo services.

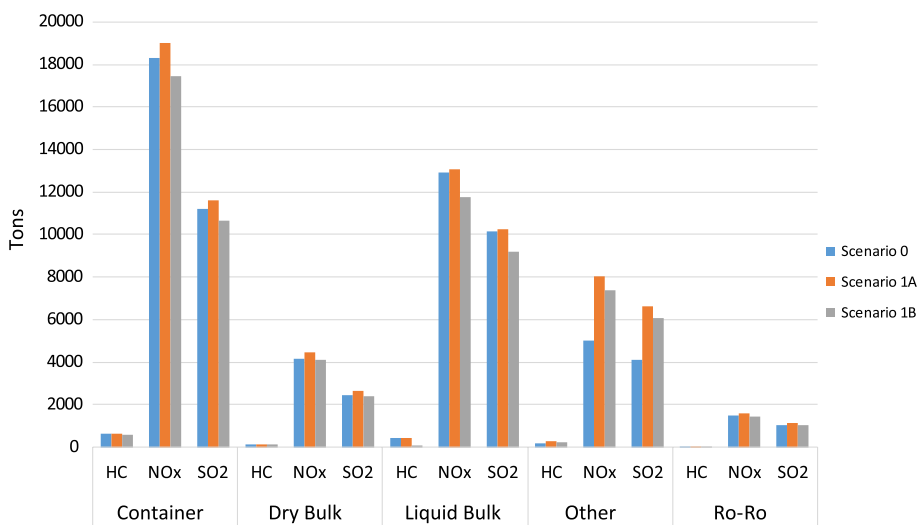
In scenario 1B, the renewal of 20% of the fleet by using innovative and green ships leads to a drastic reduction in emissions compared to scenario 0 on average equal to 8.5% for all types of transport except for the general cargo service (average reductions of 48%). Compared to scenario 1A, the reduction of emissions is on average equal to 8% for all types of pollutants and services (Figs. 6 and 7).

**Conclusions**

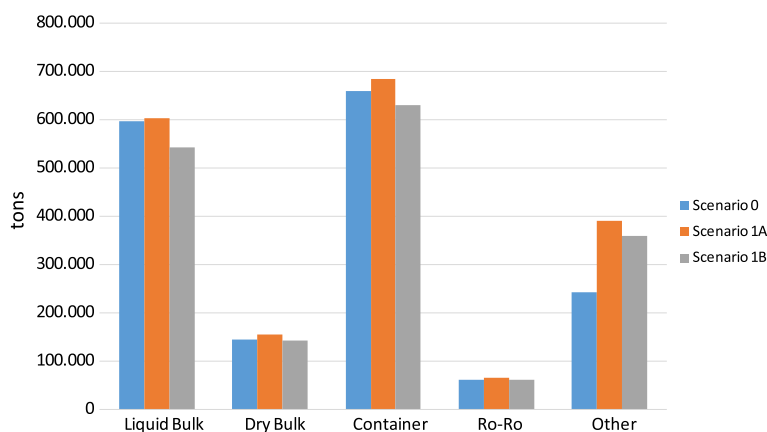
The paper has focused attention on trade flows in the Euro-Mediterranean area. The specific objective of the research has been to quantitatively analyze the extent of commercial traffic within the Mediterranean basin between the countries bordering it. By the use of data from various sources, the commercial profiles of each country have been constructed, focusing with particular attention on maritime import/export flows (liquid bulk, dry bulk, container, Ro-Ro, general cargo). In detail, the export exchange within the area has been evaluated through the composition of appropriate Origin/Destination matrices.



**Fig. 5** Scenario comparison of traffic flows



**Fig. 6** Emissions of HC, SO<sub>2</sub> e NO<sub>x</sub>. Scenario framework



**Fig. 7** Emissions of CO<sub>2</sub> in different scenarios

The collected and systematized data have been used for the specification, calibration and validation of a log-linear gravity model useful for estimating commercial traffic in the Euro-Mediterranean area.

The gravity model had been reliable in giving the actual trade flows; the results have showed a good adaptation of the model to the data of commercial use of exchanges between the countries of the Euro-Mediterranean area, confirming the importance of the variables used in the phase. specification of the same (GDP and intermodal distance). Assessments have been carried out in terms of polluting emissions into the air generated by maritime transport which made it possible to highlight the importance of projecting the maritime sector towards a green turning point that can allow a significant reduction in emissions while still guaranteeing the possibility of conveying flows by sea important goods.



Future research developments are oriented towards the calibration of the gravity model, considering the international and crossing shipping in the Euro-Mediterranean Sea, also calculating the emissions produced by ships.

The gravity models for other specific geographic areas are under elaboration in order to estimate freight flows on circumscribed basins such as the case of the Mediterranean Sea. In addition, attention will be paid, in particular, to the study of new naval technologies increasingly oriented towards Green in order to evaluate the impacts generated by the use of innovative fleets with ever lower emissions.

#### Abbreviations

CACM	Central American Common Market
CARICOM	Caribbean Community
CO <sub>2</sub>	Carbon Dioxide
EU	European Union
EU-27	European Union of 27 member states
GDP	Gross Domestic Product
GVA	Gross Value Added
HC	Hydrocarbon
LNG	Liquefied natural gas
MAGREB	Algeria, Morocco, Tunisia, and Libya
MED ECA	MEDiterranean Emission Control Area
NAFTA	North American Free Trade Agreement
NO <sub>x</sub>	Nitrogen Oxide
O/D	Origin/Destination
OECD	Organisation for Economic Co-operation and Development (
Ro-Ro	Roll On, Roll Off
SAARC	South Asian Association for Regional Cooperation
SO <sub>2</sub>	Sulphur dioxide

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#### Author contributions

The authors are part of a research group that has been involved in conceiving and carrying out the research work. Each author has collaborated with the others in every phase of the study from the acquisition of the data to the publication of the results in a continuous comparison. All authors read and approved the final manuscript.

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#### Availability of data and materials

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

#### Declarations

##### Competing interests

The authors declare that they have no competing interests.

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