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METRO

EUROPEAN UNION

Passengers and Goods flow dynamics,
Analysis of port capacity for target ships & ships energy consumption

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Summary

Introduction

In recent years, the development of road infrastructure and a constantly increasing number of vehicles has also had a positive influence on the development of maritime passenger transport.

Passenger transport on ferries, therefore, led to an important expansion of ferries and RO-PAX fleet and circulating but also to an important development of port infrastructure. In the last few years, the world fleet of ferry ships has grown in three directions: the construction of comfortable ferries relatively fast, intended for the night and fairly long routes; superfast ferries used exclusively for daytime travel and RO-PAX ferries designed primarily for the transport of commercial vehicles and for passengers and private vehicles.

In the short term, ports adapted to manage new types of ferries by providing themselves with modern technology for the sorting of large numbers of people and numerous types of vehicles. This is particularly important in the arrivals and departures of superfast catamarans due to their very short stopover in the ports. In such cases, the operations of disembarkation and embarkation of passengers are similar to those of an airport. In Croatia, the traffic with ferry ships began to develop about twenty years ago. Due to the geographical location of Dalmatia and the numerous islands, the port of Split has become the largest port on the Adriatic for passenger transport by ferry boats.

The Adriatic area, thanks to the particular conformation and the kilometers of coastline available, sees the sea-land relationship and integration as an essential element to take into account in its future development. In the Adriatic area, the state of the existing and possible connections leads to favor the sea compared to other alternatives that would require excessive infrastructure loads. The topic of relief is that of the “freeways of the sea” that represent service of marine transport alternative to ordinary practicability on road. The choice of maritime transport over road transport is, however, conditioned by several factors which are well known by a shipowner: For maritime transport to be competitive with road transport the minimum distance should be 600 km, but there is nothing to prevent the creation of maritime links at shorter distances that can best meet the needs of the market. Although the focus of the job is the leisure and not commercial component for the shipowners the presence of stable traffic of this second component is a determining factor.

1.1 Analysis of port capacities for larger ships

The Adriatic Sea is a tourist area on which there are more than 150 destinations. It is an ideal place to move for tourism or logistics, and the port of Ancona represents an important connection hub for its geographical position, in fact, over a million passengers are handled yearly. Due to the strategic position, the port of Ancona represents an important location for the Adriatic-Ionian dynamics in terms of passenger flows and for the tourism of the entire Adriatic region.

However, it must be considered that there are many alternatives for the displacements, and this must be considered within an analytical strategy on the harbor development of the entire Adriatic region.

A frequent mistake is to think that the competition is played only between realities assimilated by the same production characteristics and the same type of product, with the consequence of concentrating its efforts and investments to acquire competitiveness and defend it against other companies belonging to the same sector. Conversely, a correct reading of the competitive environment starts from the analysis not only of the competitors but of all the factors that can influence the dynamics: of those who are part of it, of which are the levers to move and so on, starting from the identification of the demand and its needs: All this applies to several fields and sectors, including that of transport: the transfer from one point to another, when not possible through its means, can sometimes be guaranteed through different solutions. Starting from the new online platforms and the habit of tourists to be able to compare more and more quickly solutions very different from each other as well as being able to easily finalize the purchase, travel options, and their suppliers are placed in a constantly changing context. Among the possible alternatives to travel in the Adriatic area are two: air and sea. Both these modes record changes in terms of both players and routes. For this reason, the knowledge and updating of what happens in these areas are even more relevant. In this context, the understanding of the performance of the port of Ancona concerning ferry traffic, about the volumes of demand appears extremely important, opening to a new and extensible reflection of interest for many ports, not only Adriatic, active in passenger traffic.

From the analysis of the geography of the ferry connections, the routes activated, companies engaged in this sector, and through the deepening of the Adriatic airports involved by this traffic is essential to define the geographical and environmental boundaries in which to insert the METRO project.

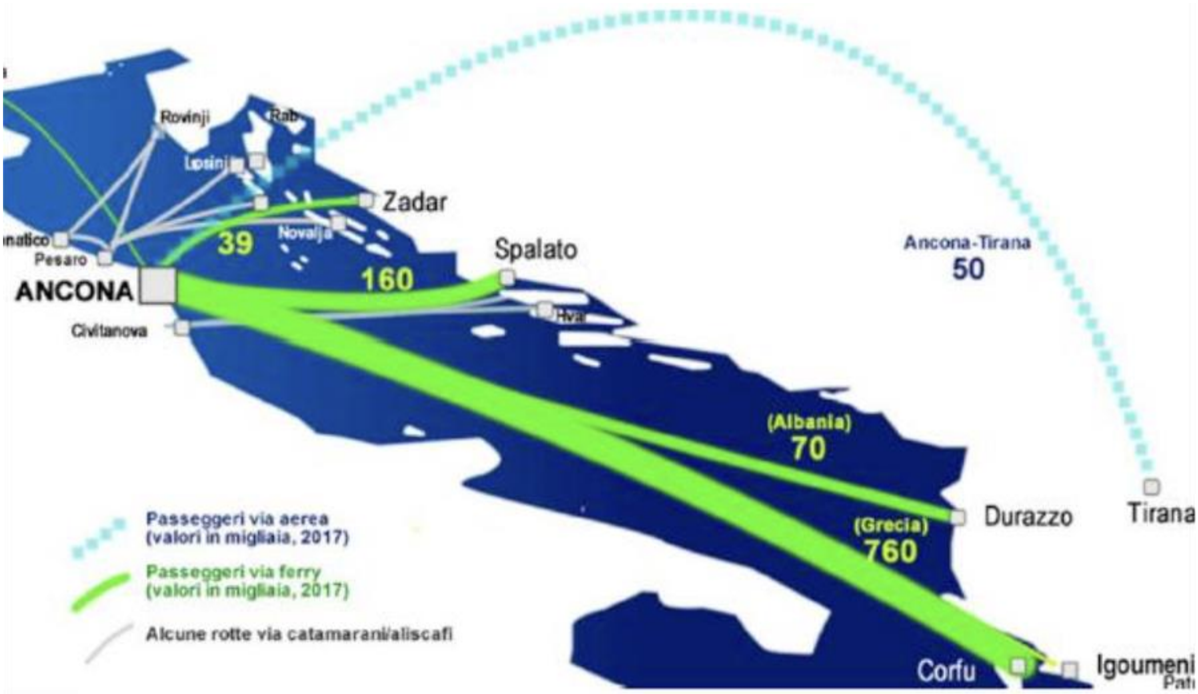

Figure 1: Passengers Flows Ancona – Croatia Source:Central Adriatic Sea Port Authority

The port of Split is the area's leader (almost 5 million domestic and international passengers in 2018) with Igoumenitsa and Zadar to follow (2.8 and 2.4 million). Among the Italian ports, Bari is in 5th positions with 1,2 million passengers; immediately after it is positioned Ancona, exceeding the threshold of the million. Rereading but the classifies for the single international traffic are the two Italian ports of Bari and Ancona with

Igoumenitsa and Durres to follow. Shifting the attention on a horizon of 10 years and focusing on the international ferry traffic in the area, it has recorded substantial stability between 2008 and 2011 followed by a net decrease between 2011 and 2012. the main ports of call of the Adriatic (13), then in 2008 they recorded approximately 7 million passengers, from 2012 they have enlivened little more than 5,5 million people, figure in decrement until 2015 (5,1 million), therefore in increase until the last years in which the enlivened passengers have been almost 6 million.

There are 14 companies that in 2018 have operated in the Adriatic-Ionian area, 10 of which are dedicated to the transport by ferry; the remaining 4 have operated with hydrofoils and catamarans.

The proposed map then compares, for the city of Ancona, the available air and ferry connections, in the first case only one to Tirana, while there are many those by water. The number of passengers traveling by air is higher than only the Ancona-Zara route.

1.2 Maritime routes between the ports of Ancona Split

The analysis the Ro-Pax routes offered between Italian port of Ancona and Croatian port of Split, and other route operated by RO-PAX ferries from Ancona to Zadar and from Bari to Dubrovnik. The routes (showed in the following figure), are managed by the Jadrolinija and SNAV.

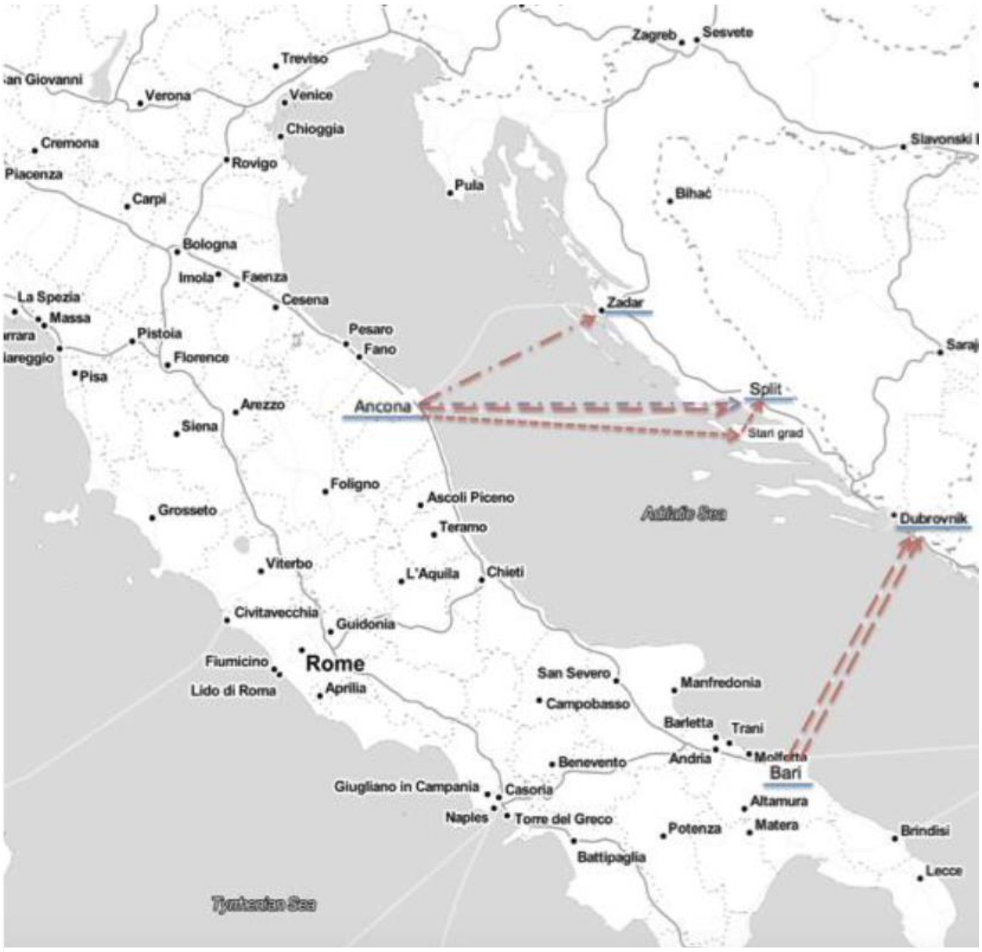

Figure 2: RO-PAX flows Jadrolinjia Ancona-Split Source: Elevante Trading & Consulting

The Ro-Pax most frequent route is Ancona – Split (328), managed with one line for the whole year by the Jadrolinija, and with one line from April to September by the SNAV.

Ancona port connects the highest number of destinations with 2 lines to Split and 1 line to Zara, and has the highest number of departures, equal to 15 in the high season. After data processing, we can see that there is a quite evident seasonality during the year:

• Low season - includes months from December to March and there is 1 active line from port of Ancona to port of Split that has an average of 2 departures per week, equal to 8% of the total departures, as shown on the above Table 1. This maritime route is managed by the Jadrolinija, and it’s the only active maritime routes for the whole year.

• Transition time includes months from April to June and from September to November. For the first months, starts to operate SNAV with Ancona – Split routes, whereas Jadrolinija starts to offer all their 4 routes. Routes increase from 1 to 5 and average of weekly departures per month increase from 6 to 12, leading to increase from 28 to 56 the total monthly departures. From September to November, decrease routes, from 5 to 3, and average of weekly departures per month from 10 to 4, leading to decrease from 45 to 19 the total monthly departures.

• High season – includes July and August, period in which increase the average of weekly departures per month from 16 to 20, reaching 23 departures and keeping them for 2 weeks. On this period 97 departures are reached. It represents 39% of the total annual departures.

Month	Weekly departures						Monthly departures	% departures of a total	Weighted average of a weekly departures	Seasonality
January	2	2	2	2	1		9	2%	2	Low season
February	1	2	2	2	1		8	2%	2	Low season
March	1	2	2	2	3		10	2%	2	Low season
April	0	5	5	7	9	2	28	6%	6	Transition time
May	6	8	9	11	6		40	9%	8	Transition time
June	5	13	13	13	12		56	13%	12	Transition time
July	0	15	16	17	20	6	74	17%	16	High season
August	17	23	23	21	13		97	22%	20	High season
September	1	11	10	11	12		45	10%	10	Transition time
October	12	10	8	7	2		39	9%	9	Transition time
November	2	4	4	4	5		19	4%	4	Transition time
December	0	2	2	2	2	0	8	2%	2	Low season
	Total annual departures						433	100%		

Figure 3: Table of Departures from Ancona to Split: Source: Elevante Trading and Consulting

From the table shown in the figure above, it is possible to observe an important seasonality regarding the number of weekly departures, with the appreciable peak in the month of August.

2.1 Port capacities and infrastructure:

From the point of view of the harbor ability, two participations stand out for the Adriatic region. Completed in the course of 2014 to Venice and Zara and fully operating from season 2015. The terminal of the highways of the sea localized in the Venetian area of Fusina has a potential ability to 1.200 ferry anniversary, composed from 4 docks for Ro-Pax, and is managed by an ad-hoc society that connects Venice Passenger terminal - with only hydrofoil and catamaran passengers to Istria to manage. The port of Gaženica was built as the port of Zadar, designed and built from scratch. Also, in this case, it operates to decongest the port located in the historical center, in which it will remain to manage traffic made of ships from the smaller tonnage - always managed from the Port Authority.
For what concern the port of Ancona, it is possible to observe in the table which is the main pier used for the RO-PAX and passengers arrives and departures:

Quays Name:	**ID Number:**	**Length mt**	**Depth mt**
Wojtyla	8	125	8,5
Wojtyla	9	110	9,5
Santa Maria	11	150	8,5
Santa Maria	12	80	8,5
Santa Maria	13	150	10,5
Repubblica	14	195	10,5
XXIX Settembre	15	200	10,5
XXIX Settembre	16	120	8,5

Tabele 1: RO-Pax quays port of Ancona Source: Personal Elaboration

Analyzing the ports of the Adriatic area it is possible to observe for the year 2018 the flows in terms of calls and passengers for each port, as presented in table 2.

Total Port Passengers and Calls	Year:2018		
Port	**Country**	**Passengers**	**Calls**
Split	HR	4.817.828	12.389
Igoumenitsa	GRE	2.677.303	12.583
Zara	HR	2.387.482	18.087
Corfù	GRE	1.472.618	12.695
Bari	ITA	1.222.940	2.258
Ancona	ITA	1.037.999	2.432
Durazzo	ALB	879.905	1.012
Dubrovnik	HR	569.776	2.177
Patras	GRE	521.349	1.265
Brindisi	ITA	492.113	1.036
Sibenik	HR	284.816	2.784
Venezia	ITA	203.996	565
Rijeka	HR	127.282	622
		Total: 16.695.407	**Total: 69.905**

Tabele 2: Passengers & Calls for the Adriatic Ports Source: Personal Elaboration

2.2 Trends and season fluctuation for the port of Ancona

The passenger transport sector is strongly subject to seasonal fluctuations, with a significant peak in the summer months, especially in July and August. As shown in the previous figure, it is possible to observe that almost 40% of total departures from the port of Ancona to Split are made in July and August. However, in this context, it should be noted that the loading capacity of the ferries is extremely higher than the number of passengers transported.
In fact, as can be seen from the table below, in the summer period RO-PAX ferries travel on average at a loading factor of between 38% and 44%, while in the winter period the loading factor drops steadily to 10-11%.
Obviously, the transport of passengers from the Italian coast to the Croatian coast and vice versa is very much subject to seasonal fluctuations, due to the fact that the destinations reachable by RO-PAX ferries are normally aimed at tourist holidays in seaside resorts, and consequently during the winter months these will be used drastically less.

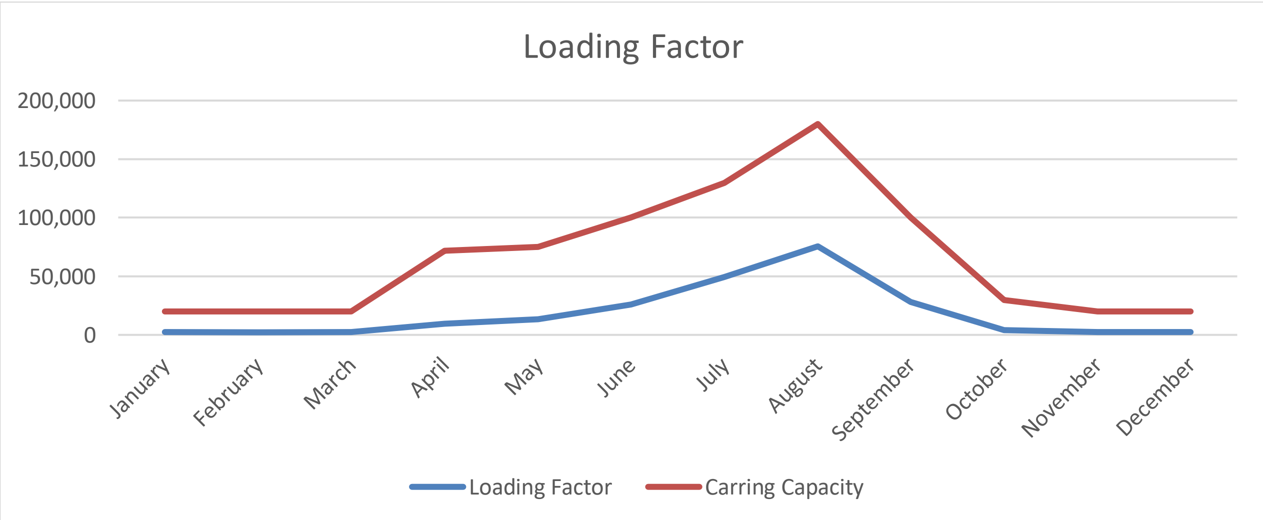

Figura 4: Graph of Loading Factor per Month on route Ancona-Split Source: Personal Elaboration

	Loading Factor	Carring Capacity	Loading Factor Percentage

January	2.380	20.000	12%
February	2.200	20.000	11%
March	2.385	20.000	12%
April	9.360	72.000	13%
May	13.500	75.000	18%
June	26.000	100.000	26%
July	49.400	130.000	38%
August	75.600	180.000	42%
September	28.000	100.000	28%
October	4.200	30.000	14%
November	2.600	20.000	13%
December	2.400	20.000	12%

Tabele 3: Loading Factor & Carring Capaciity Passengers RO-PAX port of Ancona – Personal Elaboration

As could be expected, also the owners of the ferries used have tried to adapt the number of calls to the seasonal trends, keeping however active the service also during the winter period in which the passenger flows turn out minimal, and significantly enhancing the service during the warmer months so as to adapt supply to demand.

2.3 Proposal for a new route

For its strategic position, the port of Trieste represents a hub of primary importance inside of the dynamics of the transport goods and passengers in reference not only to north-Eastern Italy, but represents a strategic center for commercial relations with European continental countries such as Germany, Austria, Hungary, and the Czech Republic.

For several years the port of Trieste, through the society participated Trieste Terminal Passeggeri, is conveying a considerable flow of the different types of ships from the cruise, that dock directly to the "Stazione Marittima", the cruise terminal in the heart of the city, adjacent to Piazza Unità, the city center. On the weekend of the summer months, the Port of Trieste was able to manage until 5 ships from the cruise in mooring, income, or escape from the port.

Moreover, the port of Trieste has been operating for several years with hydrofoils on international routes such as Trieste-Lussinpiccolo, passing through the ports of Rovinj, Poreč, and Piran.

The current infrastructure in an endowment to the port of Trieste involves that this can simultaneously manage a wide number of hydrofoils, ferries, RO-PAX, and ships from the cruise. the docks that the harbor authority could put on of the plan METRO turn out all electrified and, in a position, to operating ambivalent way is on ferries of small dimension that on RO-PAX with the largest dimensions and with adequate road access to disembarkation and embarkation operations.

For its strategic position the port of Trieste today represents the first Italian port for enlivened volumes of goods and a center of fundamental interchange with the neighboring countries of East Europe. For this reason, it has been decided to propose inside of the possible routes proposed from plan METRO also I use of ferry RO-PAX to hybrid feeding to cover a new route that directly connects the Port of Trieste to the Port of Pula. However, it must be emphasized as the infrastructure currently present near the port of Pula could return the berthing of a ferry RO-PAX difficult due to the shallowness of the seabed and the docking pier intended for international ferries not long enough for the management of a ferry the size of that considered by our

project.
In the proposal of this new route therefore it would be necessary also to include of the important infrastructural intense activities for the port of Pula that include the lengthening of the pier River, using perhaps a part of floating dock, the dredging of the seabed and a further analysis of the vehicular traffic, in order to avoid congestion of the traffic on the promenade of the Croatian city.

Route Trieste - Pula

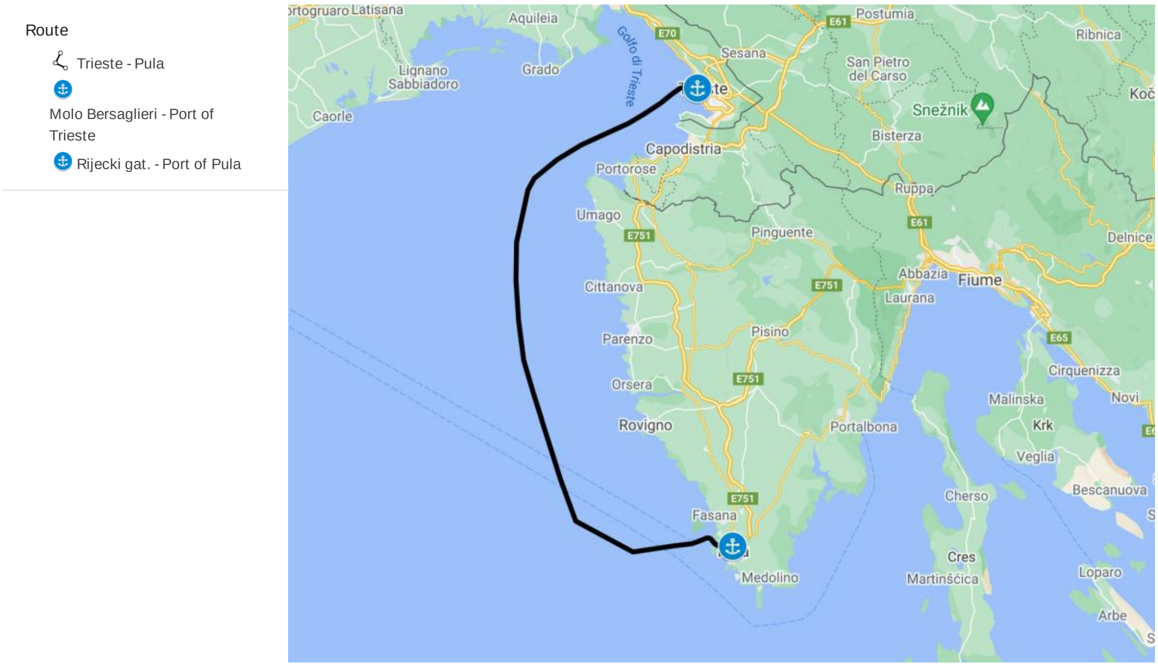

Figure 5: Maps of route Port of Trieste – Port of Pula Source: Google MyMaps – Personal Elaboration

Figura 6: Port of Pula – RO-PAX Quay

Figura 7: Port of Trieste – RO-PAX quay – possible solution

3.1 Emission Quantification Methodology:

For the analysis of energy efficiency for the Ferries used for the Brestova - Porozina route and for the Ro-Pax deputies to operate on long-haul routes, will be used the information provided in the previous Work Packages and in particular into the W.P. 3.1.

For the analysis of the emission factors, we will use the estimated annual fuel consumption proposed in theW.P.3.1.

Following the indications of the International Maritime Organization for the quantification of the emissions it is necessary to quantify the 'power factor demanded', going then to define the actual fuel consumption, which can be derived from the following formula:

$$Fuel\ Consumption = Specific\ Hourly\ Fuel\ Consumption \cdot Effective\ Hourly\ Engine\ Power$$

We can now proceed to the calculation of greenhouse gas emissions by means of two different approaches: the first based on the energy used in terms of kWh, expressed in $g_{pollutant}$ /kWh, where emissions are calculated using the following formula:

$$Hourly\ Emissions = Emission\ Factor \cdot Effective\ Hourly\ Engine\ Power$$

In the following table we will now illustrate the main emission values for the quantification of the Carbon Footprint expressed in grams per kilowatt hour for diesel engines:

Emission Factor:		$g_{pollutant}/g_{fuel}$	GWP - **100**
CO_2	Carbon Dioxide	3,114	1
Emission Factors:		g/kWh	
N2O	Nitrous Oxides	0,03	298
CH4	Methane	0,2	25
CO	Carbon Monoxide	1,04	1,8
PM10	Particle	0,01	-

Tabele 4: Ship Emission factors and Global Warming Potential – Personal Elaboration

With simple arithmetic steps, thus knowing the 'power factor required', it is possible to obtain the actual emissions for these climate-altering gases. The second approach for calculating ship emissions is the one related to actual fuel consumption. Therefore, starting from *'fuel consumption'*, it is possible to calculate the emissions produced in terms of $g_{pollutant}/g_{fuel\ consumption}$..

The arithmetic process to be followed in this case is expressed by the following formula:

Hourly Emissions = Fuel Consumption · Emission Factor

In this case the emission factor is standardized for diesel engines, from which it can be deduced that the emissions of CO_2 are equal to 3,114 g_{co_2}/g_{fuel}.

Starting from this basic information of the W.P. 3.1. and using the data on the energy efficiency of the main engines along the routes under analysis, it is possible to quantify the carbon dioxide equivalent emissions.

In quantifying the emissions for the routes under analysis, in addition to the direct emissions produced by the engines used, it could also be useful to estimate the indirect emissions: this component of the study includes the emissions deriving from the suppling of fuel oil within the transport chain. By this way, it will be essential to study the entire life cycle of diesel fuel, from the processes of extraction, processing, refining, storage, and final distribution of the fuel, in order

to concretely evaluate the indirect emissions for the transport process, in which the handling of heavy vehicles and therefore the use of fuel oil is of primary importance. Generally, this process is called “From Well to Tank” (WTT).
Focusing on the "Well to Tank" process only, the diesel production chain must be considered. To evaluate the indirect emissions of the From Well to Tank process, it is important to quantify the emissions produced by the entire oil production and processing chain, starting from extraction, through refining and finally distribution. We referred to the studies proposed by the Joint Research Center, where the indirect emissions of the WTT process will be equal to 645.17 gCO_2 eq / kg fuel. With this information it will be possible to calculate the CO_2 equivalent emissions deriving from the WTT component.

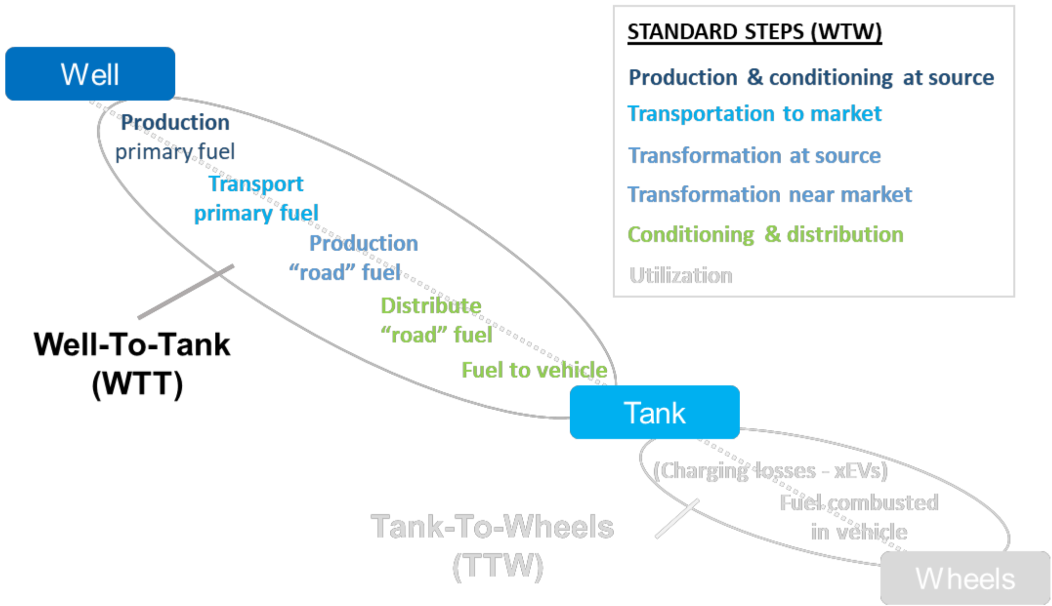

Figure 8: Well – to – Tank process Source: JRC – Joint Research Center

3.2 Brestova – Porozina: Vessels, Route and Transit Time

The route Brestova and Porozina is a round trip between two small ports located in Croatia, in the Istria Region of the island of Cres (Primorsko-goranska region). As already expressed, the route is less than 3 nautical miles and it represents a direct connection between the mainland and the island of Cres. This route is very important for the local economy in fact the larger part of the tourist that annually arrives at the island of Cres use this waterway. Cres island is reached thanks to car transportation towards Brestova in Istra and then the ferry boat to the island. As life on Cres is essentially based on tourism, it is evident the importance of one solution improving the environmental impact of transportation. For this reason, the economic and environmental proposal of the ambitious METRO project became extremely important for Croatian tourism for the entire region.

The proposal of METRO project is to adopt an integrated strategy to reduce the pollutant emissions for what concerns both the shipping part of the route and the infrastructure dedicated to the mooring of the ships. To reach this goal appear evident the need for investment in infrastructure, finalized to the electrification of the quay and on the other hand a total renovation of the ship used for this route, and this is the reason behind METRO project. If the onboard energy storage systems can strongly decrease the vessel's environmental impact during sailing, a specular approach must be applied when mooring at the port. In such a case, only a well-designed recharging infrastructure can provide the green energy for refilling the batteries. In this context, two are the aspects to be considered. On one hand, the source for recharging the onboard storage, possibly carbon-free. On the other one, the time for recovering the full battery capacity, thus at the final stage the power of the electrical infrastructure.

The nautical distance between the berths of Brestova and Porozina is about 2.7 nautical miles, and the transit time is approximately 10 minutes.

To quantify the environmental impact, it is important to analyze the vessels that operate on this route: MV Bol and MV Brestova, whose details are in Table 2 and 3.

Voyage particulars	Sailing Speed	Distance	Duration - Navigation in open sea	Duration - Maneuvering	Duration - Total navigation	Duration - Berth
Both ships	11 kts	2,7 M	15 min	10 min	35 min	15min/4hrs

Table 5: Route and Transit time Brestova – Porozina Source: Personal Elaboration

Main Particulars	**M/V *Bol*:**	**M/V *Brestova*:**
LOA	95.4 m	58.17 m
Breadth	20 m	16.8 m
Draught	2,3 m	2,7 m
GT	2330	2315
DWT	1.000 t	482 t
Build	2006	1985
Capacity vehicles/passengers	176 / 600	70 / 338
Engines	4 x MAN D28482LE402 TSP F240, total: 1.412 kW	2 x YANMAR T 260 ET, total: 2.200 kW
Speed	12 kts	12 kts

Table 6: Vessel for route Brestova Porozina Source: Personal Elaboration

Figure 9 & 10: MV Bol & MV Porozina

To try to quantify the emission for this route, another essential information is the number of passes through that are operated by the MV Bol and the MV Brestova every year, and we could find this information directly on the web site of the Jadrolinjia that directly manage this route. From this information we could notice that for the month of January, February, March, April, May, October, November, and December are operated 8 runs per day, 4 for each vessel and during the summer period are operated 12 runs per day, six for each ship. Resting upon this hypothesis it is possible to define the total number of run that any ship has done during a year: 1776.

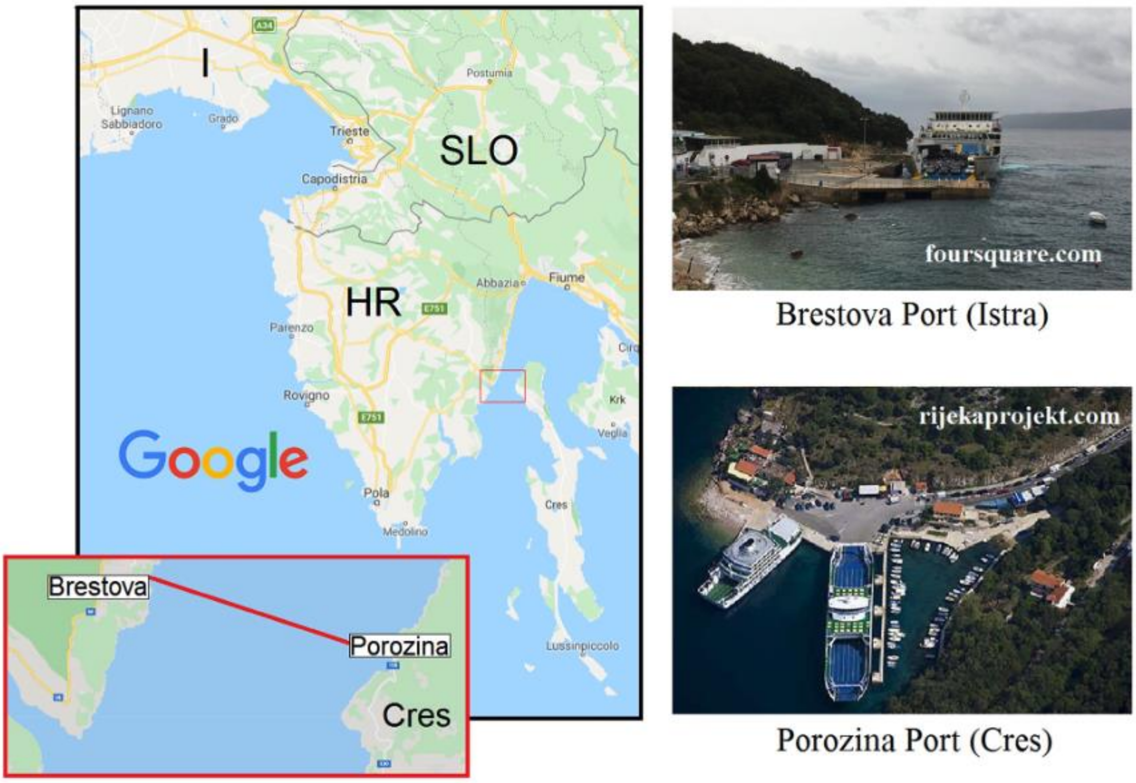

Figure 11: Port of Brestova – Porozina

The Brestova Porozina route can handle over 1,650,000 passengers from the mainland to the island of Cres and over 430,000 cars. The flow of passengers reaches its peak in the summer months, where, in the period from June to September, the Brestova Porozina line is equipped to move up to 850,000 people, about 170,000 people per month.

3.3 Quantification of the Emissions Brestova – Porozina:

The information presented previously represents the pillars of the analysis of environmental impacts and the quantification of the emissions that will be operated in this paragraph.

As already mentioned during the methodological introduction, the quantification of the emissions for the route Brestova Porozina will be managed using at the same time the information relative to the fuel consumption and to the kW/h provided by the main engines of the ships, for both the direct emissions and the indirect emissions.

It is important to highlight that, to quantify the emission we will use the global warming potential method: any pollutant emission different from the Carbon Dioxide will be weighted for their global warming potential. This measure represents the heat absorbed by any greenhouse gas in the atmosphere as a multiple of the heat that would be absorbed by the same mass of carbon dioxide, giving us a result in a single measure unit: the Carbon Dioxide equivalent (CO_{2e}).

From the W.P. 3.1 is possible to observe a concrete estimate of the average fuel consumption for ferries operating on the route Brestova-Porozina. This analysis suggests that the average annual consumption for each of these two ferries is about 360 tons of fuel oil and that the average power delivered during the journey expressed in kWh is 439,92.

The number of runs that each vessel carries annually is equal to 3532, it is possible to quantify the fuel consumption for a single route, that is 103,06 liters of gasoline per run.

Using these data, it is possible to quantify the emissions in terms of CO_2 equivalent as presented in the following table.

Emission Factor:		$g_{pollutant}/g_{fuel}$	GWP - 100
CO2	Carbon Dioxide	3,114	1
Emission Factors:		g/kWh	
N2O	Nitrous Oxides	0,03	298
CH4	Methane	0,2	25
CO	Carbon Monoxide	1,04	1,8

Table 7: Emission Factor Diesel Engine Source: Personal Elaboration

Emission Factor:		$g_{pollutant}/g_{fuel}$	GWP – 100 (g)
CO2	Carbon Dioxide	320.921,8	320.921,8
Emission Factors:		g/kWh	
N2O	Nitrous Oxides	13,2	3932,9
CH4	Methane	88,0	2199,6
CO	Carbon Monoxide	457,5	823,5
		Total $CO_{2equivalent}$ (KG)	327,88

Table 8: Emission Factor average route Brestova – Porozina Source: Personal Elaboration

The direct emissions for a single run from Brestova to Porozina are equal to 327,88 kg of CO_2 equivalent.

Now it is also possible to define the undirect emission for the single route. As presented before, the process “from – well – to – tank”, represents the emission related to the supplying of the fuel, and it is possible to quantify those emissions as 327,88 kg CO_2 eq fuel. We can therefore estimate the indirect emissions related to the supply of the fuel equal to 66,49 kg of CO_2 per single run.

We can therefore quantify the annual emissions produced on the Brestova - Porozina route for each individual vessel by multiplying the direct and indirect emissions produced on the individual route by the number of runs performed: the direct emissions annually are equal to 1.158.064 kg CO_2 equivalent while the indirect emissions I reach 234.842 kg CO_2 equivalent.

Once the emissions produced by ships with traditional fueling it has been estimated, a comparison was made with reference to the hybrid ferry proposed by the METRO project. Always taking into consideration the estimates made by Wartsila in the W.P. 3.1 it is possible to observe how the annual consumption for a hybrid ferry on the same route and under the same conditions is equal to 210 tons of diesel per year against the 360 tons of fuel currently used.
Using the previously proposed calculation methodology, it is possible to quantify the direct and indirect emissions for the single route: direct emissions, equal to 193,87 kg CO_2 equivalent, with estimated fuel consumption of 60,02 liters and indirect emissions equal to 38,72 kg CO_2 equivalent.
From this information, we can therefore calculate the direct emissions produced annually for the hybrid ferry, equal to 684.737 kg CO_2 equivalent and indirect emissions equal to 136.776 kg CO_2 equivalent per year.
The use of the hybrid ferry on the Brestova Porozina route would therefore lead to an annual reduction of direct emissions equal to 473.300 kg CO_2 equivalent and indirect emissions equal to 98.060 kg CO_2 equivalent.

3. 4 Ancona – Split: Vessels, Route and Transit Time

The second route selected as a case study for METRO project is a long rage connection between the Port of Ancona (Italy) and the Port of Split (Croatia), crossing the Adriatic Sea with a distance of approximately 100 nautical miles. A preliminary evaluation identified the two-reference vessel for this route: MV Aurelia and MV Marko Polo, whose details are in Table 6:

Main Particulars	**M/V *Aurelia*:**	**M/V *Marko Polo*:**
LOA	147,9 m	128,1 m
Breadth	25,4 m	19,6 m
Draught	5,8 m	6,2 m
GT	22.518	10.154
DWT	3.250 t	1.132 t
Build	1980	1973
Capacity vehicles/passengers	610/2280	270/1000
Engines	2 x GMT A420 16V Diesel Total: 14.120 kW	4 x STORK WERKSPOOR 8TM410 - 4T Total: 15.000 kW
Speed max/avg	19,5/15,5 kts	19/16 kts

Table 9: Vessel Route Split – Ancona Source: Personal Elaboration

As it was done for the definition for the propulsion system of a double-ended ferry, an analysis of the navigation data has been done. This has been achieved by collecting the position and the speed of the selected vessels with an average a sampling rate of 15 minutes, in a period from 1 Jan 2016 to 1 June 2019. The final dataset amount to nearly 125 thousand samples, allowing to define the real ship speed profile with good accuracy.

For this route the algorithm started with the outgoing from Split harbour, then the vessel is accelerating reaching 16 knots (cruise speed) continuing, for some voyages, with slow steaming that means a reduction of speed, around 13 knots. After, that the ship starts maneuvering to enter in Ancona's dock where the vessel will be moored for several hours waiting to come back to Split with a similar sequence of operating modes but with a slightly different duration.

Departure	**Destination**	**Repetitions**	**Average distance [nm]**
Ancona – Italy (IT) (MV Aurelia)	Split – Croatia (MV Aurelia)	208	97,01
Split - Croatia (HR) (MV Aurelia)	Ancona – Italy (IT) (MV Aurelia)	222	87,3
Ancona – Italy (IT) (MV Marko Polo)	Split – Croatia (MV Marko Polo)	263	91,3
Split – Croatia (MV Marko Polo)	Ancona – Italy (IT) (MV Marko Polo)	279	92,4

Table 10: Ancona – Split Vessel, runs and distance Source: Personal Elaboration

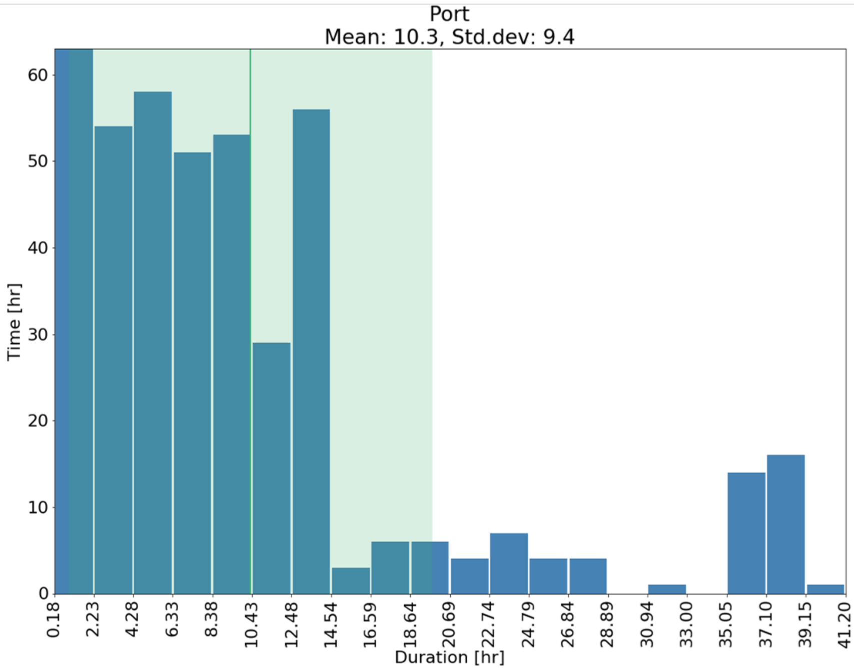

Figure 12: Transit time Route Ancona - Split

The transit time to get from Ancona to Split and vice versa is on average 10 hours of navigation as can be seen in the figure above.

By analyzing the number of repetitions carried out in the span under analysis from 01/01/2016 to 01/06/2019 and considering that the average of runs for each ship is 243, it is possible to define the annual average trips performed by each ship to 69.5 which we will approximate to 70.

In this case, we don't have the average kWh produced by any ship so, for the quantification of the emissions we will need the hypothesis that the energy efficiency of any vessel is near 60%.

The Ancona-Split route can handle over 229.600 passengers from the Port Ancona to Port of Split and over 61,600 cars per year.

3.5 Quantification of the Emissions Ancona - Split:

The proposed emission analysis for the Ancona (IT) Split (HR) route takes over the concepts set out in paragraphs 3.1 and 3.3 above and aims to quantify direct and indirect emissions.
Every year every vessel in analysis has carried out 70 runs per year on average, for an average consumption of 6750 tons of fuel.
The second basic hypothesis concerns the power supplied by the engines: with a maximum capacity of 14560 kWh and an energy efficiency of 60% it is possible to define kWh produced during navigation equal to 8736 kWh.
It is important to highlight that, to quantify the emission we will use the global warming potential method: any pollutant emission different from the Carbon Dioxide will be weighted for their global worming potential. This measure represents the heat absorbed by any greenhouse gas in the atmosphere as a multiple of the heat that would be absorbed by the same mass of carbon dioxide, giving us a result in a single measure unit: the Carbon Dioxide equivalent (CO_2e).
Starting from this information and knowing the emission factors, it is possible to quantify the direct emissions for each single route.

Emission Factor:		$g_{pollutant}/g_{fuel}$	**GWP - 100**
CO2	Carbon Dioxide	3,114	1
Emission Factors:		g/kWh	
N2O	Nitrous Oxides	0,03	298
CH4	Methane	0,2	25
CO	Carbon Monoxide	1,04	1,8

Table 11: Emission Factors Source: Personal Elaboration

Emission Factor:		gpollutant/gfuel	GWP – 100 (g)
CO2	Carbon Dioxide	96.285.714,29	299.833.714,3
Emission Factors:		g/kWh	
N2O	Nitrous Oxides	262,08	78099,84
CH4	Methane	1747,2	43680
CO	Carbon Monoxide	9085,44	16353,792
		Total $CO_{2equivalent}$ (KG)	299.971,85

Table 12: Emission Factor Route Ancona - Split Source: Personal Elaboration

The direct emissions for a single run from Ancona (IT) – Split (HR) is equal to 299.971,85 kg of CO2 equivalent.
Now it is also possible to define the undirect emission for the single route. As presented before, the process “from – well – to – tank”, represents the emission related to the supplying of the fuel, and it is possible to quantify those emission as 645.17 gCO2 eq / kg fuel. We can therefore estimate the indirect emissions related to the supply of the fuel equal to 62.120,65 kg of CO2 per single run.
We can therefore quantify the annual emissions produced on the Ancona – Split route for each individual vessel by multiplying the direct and indirect emissions produced on the individual route by the number of runs performed: the direct emissions annually are equal to 20.998.029 kg CO2 equivalent while the indirect emissions I reach 4.348.445 kg CO2 equivalent.
Once the emissions produced by ships with traditional engine it has been estimated, a comparison was made in reference to the hybrid Ro-Pax Vessel proposed by METRO project. Taking again in consideration the estimates made by Wartsila in the W.P. 3.1 it is possible to observe how the annual fuel consumption for a hybrid Ro-Pax operating on the same route and under the same conditions is equal to 3930 tons of diesel per year against the 6750 tons of fuel currently used.

Using the previously proposed calculation methodology, it is possible to quantify the direct and indirect emissions for the single route: the direct emissions are equal to 174.978,75 kg CO2 equivalent, with an estimated fuel consumption of 56.142,86 liters and indirect emissions equal 36.221,69 kg CO2 equivalent.
From this data we can therefore calculate the direct emissions produced annually for the hybrid ferry, equal to 12.248.512 kg CO2 equivalent and indirect emissions equal to 2.535.518 kg CO2 equivalent per year.
The use of the hybrid ferry on the Brestova Porozina route would therefore lead to an annual reduction of direct emissions equal to 8.749.516 kg CO2 equivalent and indirect emissions equal to 1.812.928 kg CO2 equivalent.
At a unitary level, the savings in term of Carbon Dioxide equivalent for each single trip are equal to approximately 125,000 kg direct emissions and 26,000 kg for indirect emissions.

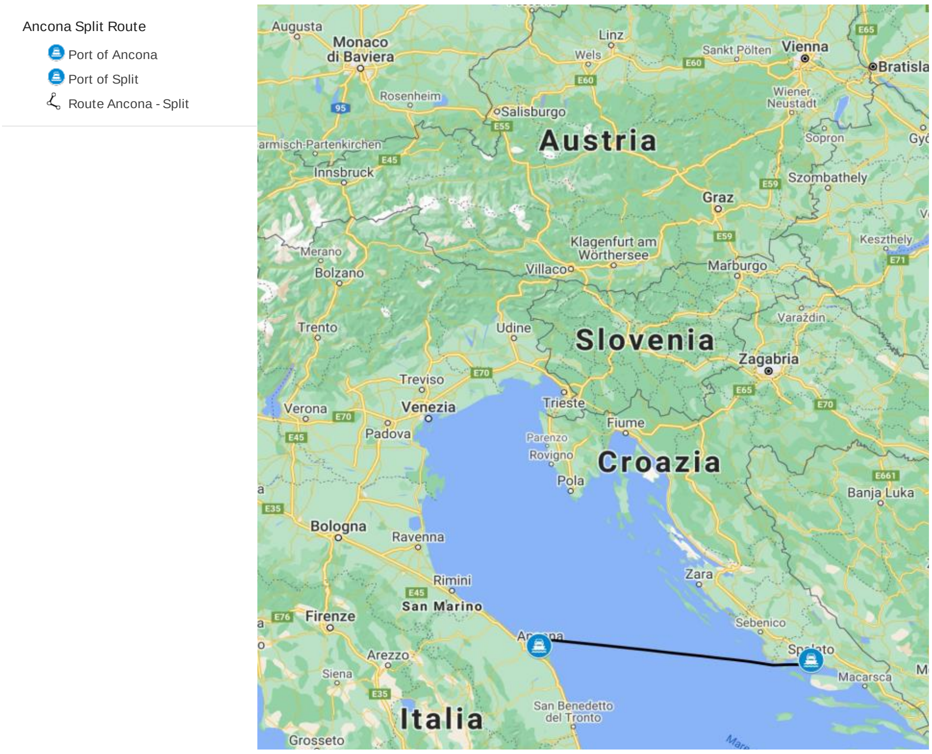

Figure 13: Ancona – Split Route Source: Google MyMaps - Personal Elaboration

References

- UNCTAD, *Review of maritime transport, 2015*, 2015
- http://www.ecotransit.org
- Ship Emissions Tookit, Guide NO.01, Rapid Assessment of ship emissions in the national Context, GleMEEP, Institute of Marine Engineering, Science and Technology (IMarEST), IMO International Maritime Organization, 2018
- Third IMO Greenhous Gas Study, 2014 – International Maritime Organization
- https://porto.ancona.it/files/Banchine%282%29.pdf
- Risposte Turismo per Autorità di Sistema Portuale del Mar Adriatico Centrale: Ferries & Avio – scenario, concorrenza e azioni