10.5281/zenodo.3989026

Interreg Italy - Croatia GUTTA

EUROPEAN UNION

Project	GUTTA
Work Package number	3
Work Package title	Strategic potential for a greener and more integrated CB maritime mobility
Deliverable number	3.1.2.
Deliverable title	Report on CB maritime traffic data
Deliverable Responsible Partner	MMPI
Deliverable Lead authors	Gianandrea Mannarini (Euro-Mediterranean Center on Climate Change, CMCC), Davor Deželjin (Republic of Croatia, Ministry of the Sea, Transport and Infrastructure, MMPI)
Deliverable Contributors	Mladena Maračić (formerly at MMPI)
Deliverable due date	2019-09-30
Deliverable latest review date	2020-03-25

Table of contents

Executive Summary

This report provides an analysis of existing RoPax maritime traffic between Italy and Croatia and a quantitative analysis of a new connectivity scenario with respect to both route duration and environmental impact.

The existing traffic is described by means of both Croatian Integrated Maritime Information System (CIMIS) and Automatic Identification System (AIS) information.

The new link is assessed both in terms of route duration and CO2 emissions (both per vehicle or per passenger) through a Pareto efficiency analysis. Both freight and passenger transportation are considered.

1. Introduction

The GUTTA project proposal (submitted in July 2017) stated that "The Adriatic Region shows considerable disparities in East-West mobility patterns. The Southern edge in particular does not allow direct terrestrial connections and is scarcely served by TEN-T corridors, hampering the mobility of both freights and passengers. Ferry routes directly connect just a limited number of ports on both sides of the basin, forcing longer journey legs by the other transport modalities. This does not only come at the costs of passenger comfort and travel time, but also of environmental impact, as the other transport modalities typically have a stronger carbon footprint than the maritime one."

Therefore, the GUTTA project includes among its Specific Objectives (SO) "To facilitate the establishment of at least one new CB maritime link" (GUTTA SO3).

The present report provides a contribution to SO3 by means of an objective assessment of the existing Italy-Croatia RoPax connections and a quantitative analysis of various connectivity scenarios with respect to both route duration and environmental impact.

The report is organized into two sections devoted to the description of present-day connectivity picture (Sect.2 through CIMIS and Sect.3 through AIS data) and a section on analyses for the possible new route (Sect.4). Key findings are summarized in the conclusions (Sect.5).

All acronyms and shortcuts are defined in the public GUTTA Glossary:
www.doi.org/10.5281/zenodo.3667198

2. CIMIS

Croatian integrated maritime information system (CIMIS) system has been created for shipping companies, their agents, Port Authorities, harbourmasters offices and their branch offices. Its primary function is to simplify administrative practices when a ship enters or leaves the port. Per the European Directive 2010/65/EU, shipping companies or their agents are supposed to send electronically all documentation and other forms that are necessary when the ship arrives or leaves, while Harbour master offices and its branch offices check the documentation or approve it, and can release necessary permissions via a web-application.

The dataset provided by MMPI for GUTTA includes data relative to 6 Ro-Pax vessels that sailed between Italy and Croatia in a period of more than two years starting in 2017. The structure of related datasets is described in the Sect.3.1 and their information content is analyzed in Sect.3.2.

3.1 Structure

The database is organized into two datasets provided by MMPI, referring to the same voyages and dates. However, one dataset (D1) includes freight information (weight and number of units) while the other one (D2) includes passenger information. The period considered (from 2017-01-04 [1] to 2019-05-20[2]) includes 867 days, or about 2.38 years.

The datasets are organized into seaports. Thus, the voyage phases (arrival, departure) do not refer to the vessel voyages but to the calls at the actual port. The ports with full-featured CIMIS information (departures/arrivals, unloads/transits/loads) are 4 (the ones listed with International Seaport code in Tab.1), while the datasets also include other 4 Croatian and 5 Italian ports linked to them.

Table 1 Seaports included in the CIMIS datasets; the ones with seaport code are featured in the database.

Port Code	Port location	Port type	Lat	Lon
HR202	Gaženica	Cargo and passenger port	44.095390	15.268980
HR479	Split	City port	43.508133	16.440193
HR365	Stari Grad	Cargo port	43.183994	16.599251
HR489	Gruž- Dubrovnik	Cruise and ferry port	42.650661	18.094423
	Trogir	Shipyard		
	Rjeka			
	Kostrena	Shipyard		
	Vis	City port/ Gas station		
	Ancona			
	Bari			
	Brindisi			
	Napoli			

In the period considered, following 6 RoPax vessels called at these harbours:

[1] Julian day 2457758
[2] Julian day 2458624

Table 2 RoPax vessels included in the D1 and D2 datasets.

Vessel name	Operator	IMO number	MMSI
Aurelia	SNAV	7602120	209510000
Dubrovnik	Jadrolinjia	7615048	238143000
Marko Polo	Jadrolinjia	7230599	238144000
Zadar	Jadrolinjia	9021485	238201000
GNV Azzura	Grandi Navi Veloci	7826790	24723770
Red Star 1	-	6511128	372589000

Each dataset includes the following fields:

Table 3 CIMIS dataset fields.

Field name	Field explaination	Field units or enumeration values
Port name	Port of call	
Previous port	Port of previous call	
Port next	Port of next call	
ATA	Actual Time of Arrival at port of call	
ATD	Actual Time of Departure from port of call	
Type Cargo	Type of vehicles transported	Passenger buses
		Passenger vehicles, motorcycles and accompanying trailers/caravans
		Road freight vehicles with accompanying trailers
Load/Unload	Flag relative to the type of operation	{load/unload/transit}
Unload_TNE	Weight of unloaded cargo	tons
Unload_No Unit	Number of items of cargo unloaded	
Transit _TNE	Weight of cargo in transit	tons
Transit_No Unit	Number of items of cargo in transit	
Load_TNE	Weight of loaded cargo	tons
Load_No Unit	Number of items of cargo loaded	

3.2 Analysis

The dataset introduced in Sect.3 are here analyzed by means of Excel Pivot tables. Related analysis of freight and passenger flows is reported in Sect. 3.2.1, while the topological analysis of the sailed routes follows in Sect.3.2.2.

3.2.1. Flow figures

The flow analysis is distinguished between freights (D1 database) and passengers (D2). For both types, the Pivot tables are organized in order to display the following hierarchy of keys:

- The 4 main Croatian seaports of Tab.1 and the shipyard of Trogir
- The 6 RoPax vessels of Tab.2
- The seaport of origin or destination of the voyages (may or may not be one of those in Tab.1)

Then, total counts for the unload/transit/loads are computed.

3.2.1.1. Freights

The freight tables (Tab.4-5) allows to make following observations:

- Transit of freights (vehicles) just occurs at the seaports of Stari Grad and Split
- The most used ports are Split, Dubrovnik, and Zadar
- The traffic in Split is mainly attributed to the Aurelia and Marko Polo vessels
- There was just one RoPax voyage from outside the Adriatic Sea (GNV Azzurra arriving from Naples on May 12, 2019 and then leaving to Ancona)
- Starting from Split, Marko Polo also called at Vis and Rijeka

Row Labels	Sum of UNLOAD_NO UNIT	Sum of TRANSIT_NO UNIT	Sum of LOAD_NO UNIT	Count of VOY_ID
Gaženica - Cargo and Ferry Port	**8023**	**0**	**8638**	**475**
ZADAR	**8023**	**0**	**8638**	**475**
Ancona	8023	0	8638	475
Gruž - Dubrovnik Cruise and Ferry Port	**12261**	**0**	**15256**	**978**
DUBROVNIK	**12261**	**0**	**15256**	**978**
Bari	12261	0	15256	978
Split - City Port	**41448**	**340**	**42761**	**2922**
AURELIA	**20237**	**0**	**20467**	**1224**
Ancona	20237	0	20467	1224
DUBROVNIK	**2757**	**0**	**2745**	**255**
Ancona	2757	0	2745	255
GNV AZZURA	**140**	**0**	**239**	**21**
Ancona	140	0	131	18
Naples	0	0	108	3
MARKO POLO	**18314**	**340**	**19310**	**1422**
Ancona	18314	340	19310	1422
Stari Grad - Cargo Port	**634**	**1319**	**0**	**31**
AURELIA	**634**	**1319**	**0**	**31**
Ancona	634	1319	0	31
Grand Total	**62366**	**1659**	**66655**	**4406**

Table 4 Freights pivot table with the ports of origin (e.g vessel ZADAR calls from Ancona).

Row Labels	Sum of UNLOAD_NO UNIT	Sum of TRANSIT_NO UNIT	Sum of LOAD_NO UNIT	Count of VOY_ID
Gaženica - Cargo and Ferry Port	**8023**	**0**	**8638**	**475**
ZADAR	**8023**	**0**	**8638**	**475**
Ancona	7979	0	8638	471
Split - City Port	44	0	0	4
Gruž - Dubrovnik Cruise and Ferry Port	**12261**	**0**	**15256**	**978**
DUBROVNIK	**12261**	**0**	**15256**	**978**
Bari	12211	0	15256	972
Split - City Port	50	0	0	6
Split - City Port	**41448**	**340**	**42761**	**2922**
AURELIA	**20237**	**0**	**20467**	**1224**
Ancona	20237	0	20467	1224
DUBROVNIK	**2757**	**0**	**2745**	**255**
Ancona	2591	0	2745	248
Shipyard VIKTOR LENAC - Kostrena	166	0	0	7
GNV AZZURA	**140**	**0**	**239**	**21**
Ancona	140	0	239	21
MARKO POLO	**18314**	**340**	**19310**	**1422**
Ancona	14802	0	15654	1255
Gaženica - Cargo and Ferry Port	54	0	0	2
Port of Rijeka	50	0	0	3
Stari Grad - Cargo Port	3199	340	3454	149
Vis - City Port	135	0	130	9
Vis - Gas Station	74	0	72	4
Stari Grad - Cargo Port	**634**	**1319**	**0**	**31**
AURELIA	**634**	**1319**	**0**	**31**
Split - City Port	634	1319	0	31
Grand Total	**62366**	**1659**	**66655**	**4406**

Table 5 Freights pivot table with the ports of destination (e.g vessel ZADAR leaves to both Ancona and Split- City Port).

3.2.1.2. Passenger

The passenger tables (Tab.6-7) allows to make identical observations than for freights:

- Transit of passengers just occurs at Stari Grad and Split
- The most used ports are Split, Dubrovnik, and Zadar
- The traffic in Split is mainly attributed to the Aurelia and Marko Polo vessels
- The “Red Star 1” vessel called at the shipyard of Trogir on June 26, 2018, sailing from and returning to Brindisi afterwards.
- The “Dubrovnik” vessel called at the shipyard of Kostrena in February 2017, 2018, and 2019, each time sailing from Ancona

Row Labels	Sum of Unload'	Sum of Transit'	Sum of Load'	Count of VOY_ID
Brodogradilište BRODOTROGIR	**0**	**5**	**0**	**1**
RED STAR 1	**0**	**5**	**0**	**1**
Brindisi	0	5	0	1
Gaženica - teretna i putnička luka	**37171**	**0**	**39727**	**123**
ZADAR	**37171**	**0**	**39727**	**123**
Ancona	37171	0	39727	123
Gruž - putnička luka (Dubrovnik)	**63734**	**0**	**72161**	**186**
DUBROVNIK	**63734**	**0**	**72161**	**186**
Bari	63734	0	72161	186
Split - bazen Gradska luka	**175494**	**1509**	**172143**	**559**
AURELIA	**94243**	**409**	**95159**	**233**
Ancona	94243	409	95159	233
DUBROVNIK	**7585**	**0**	**8242**	**57**
Ancona	7585	0	8242	57
GNV AZZURA	**578**	**0**	**930**	**4**
Ancona	578	0	665	3
Napoli	0	0	265	1
MARKO POLO	**73088**	**1100**	**67812**	**265**
Ancona	73088	1100	67812	265
Stari Grad - teretna luka	**2379**	**6020**	**0**	**8**
AURELIA	**2379**	**6020**	**0**	**8**
Ancona	2379	6020	0	8
Grand Total	**278778**	**7534**	**284031**	**877**

Table 6. Passenger pivot table with the ports of origin (with the ports of origin (e.g vessel RED STAR 1 calls from Brindisi).

Row Labels	Sum of Unload'	Sum of Transit'	Sum of Load'	Count of VOY_ID
Brodogradilište BRODOTROGIR	**0**	**5**	**0**	**1**
RED STAR 1	**0**	**5**	**0**	**1**
Brindisi	0	5	0	1
Gaženica - teretna i putnička luka	**37171**	**0**	**39727**	**123**
ZADAR	**37171**	**0**	**39727**	**123**
Ancona	37045	0	39727	121
Split - bazen Gradska luka	126	0	0	2
Gruž - putnička luka (Dubrovnik)	**63734**	**0**	**72161**	**186**
DUBROVNIK	**63734**	**0**	**72161**	**186**
Bari	63584	0	72161	184
Split - bazen Gradska luka	150	0	0	2
Split - bazen Gradska luka	**175494**	**1509**	**172143**	**559**
AURELIA	**94243**	**409**	**95159**	**233**
Ancona	94243	409	95159	233
DUBROVNIK	**7585**	**0**	**8242**	**57**
Ancona	7220	0	8242	54
Brodogradilište VIKTOR LENAC - Kostrena	365	0	0	3
GNV AZZURA	**578**	**0**	**930**	**4**
Ancona	578	0	930	4
MARKO POLO	**73088**	**1100**	**67812**	**265**
Ancona	59506	0	64654	231
Benzinska postaja Vis	180	0	0	1
Gaženica - teretna i putnička luka	132	0	0	1
Rijeka - bazen Rijeka	194	0	0	1
Stari Grad - teretna luka	12574	1100	3158	29
Vis - putnička luka	502	0	0	2
Stari Grad - teretna luka	**2379**	**6020**	**0**	**8**
AURELIA	**2379**	**6020**	**0**	**8**
Split - bazen Gradska luka	2379	6020	0	8
Grand Total	**278778**	**7534**	**284031**	**877**

Table 7. Passenger pivot table with the ports of destination (with the ports of origin (e.g vessel RED STAR 1 leaves to Brindisi).

3.2.2. Tube-like map

The D1 and D2 datasets, besides providing quantitative information on the freight and passenger flow, also define the topology of the RoPax connections in the Adriatic Sea. Apart from very occasional calls at the shipyards of Trogir and Kostrena, and the Red Star 1 voyage to Brindisi, there are 3 Italian and 6 Croatian seaports involved in the RoPax voyages.

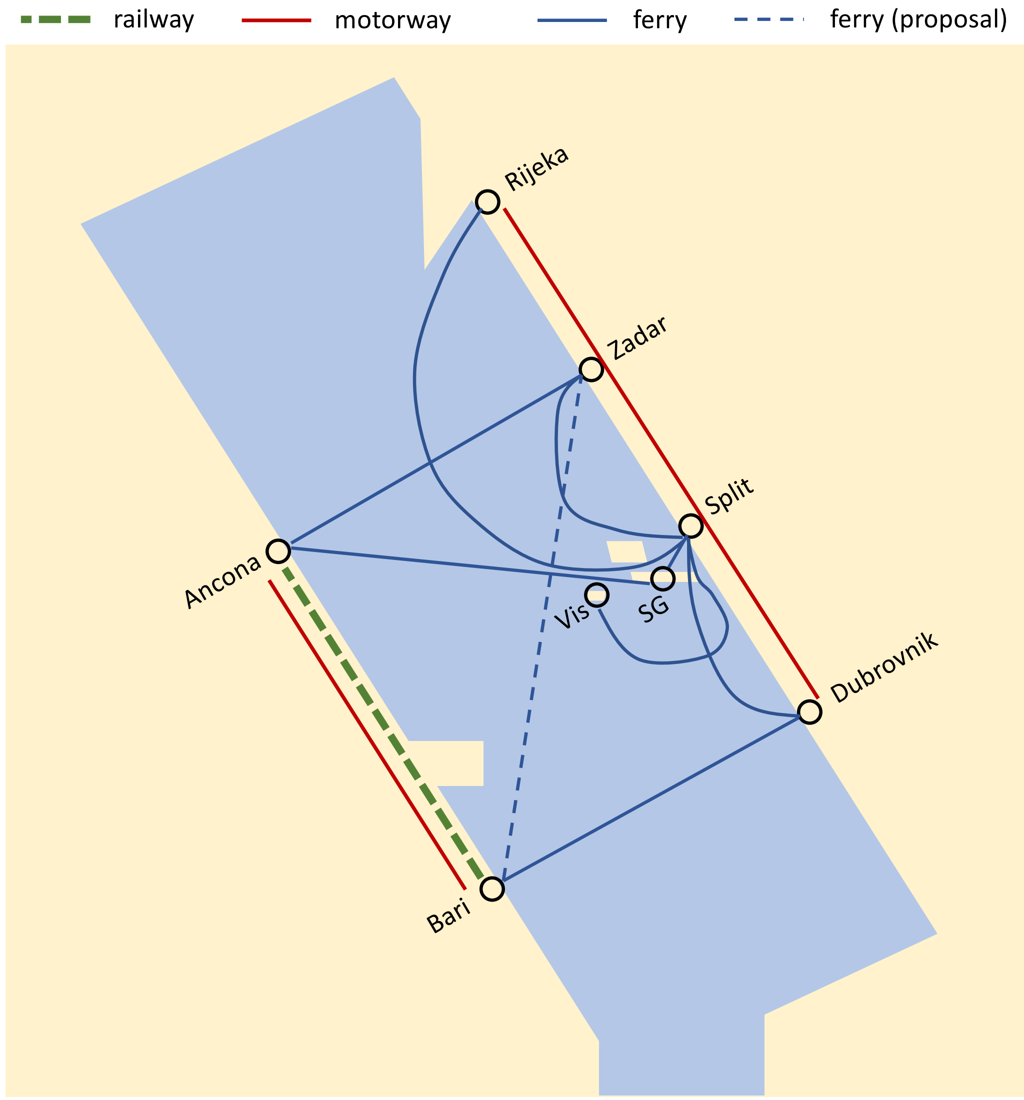

Figure 1 "Tube-like" map of the RoPax routes in the Adriatic Sea, as resulting from the CIMIS datasets provided by MMPI, with the proposal of a new CB route, resulting from Sect.4 of this report. SG is a shortcut for Stari Grad.

The topology of the maritime links is visualized by means of a "tube-like" map in Fig.1. This kind of representation puts the actual geographic information in the background (e.g., the shape of the Adriatic basin is only sketched on the tube-like map), in order to highlight the topology of the connections. Also from the tube-map, the system of seaports around Split (i.e., the Split city port and the ports on the islands of Hvar (Stari Grad), and Vis) clearly appears as a maritime hub, not only for Croatia but for the entire Adriatic basin. This holds just for the RoPax traffic, while for instance for cruise or cargo vessel the hub ports may be other ones. On the Western side, only Ancona is linked to more than one Croatian port, and this is through only seasonal (summer) voyages to Zadar.

3. AIS

While CIMIS data take the viewpoint of the harbour, Automatic Identification System (AIS) data refer to the individual vessel. In fact, each vessel is identified in terms of AIS messages through a dedicated code, called “MMSI number” (cf. Tab.2). According to the IMO-SOLAS Convention, must be operational on all ships of over 300GT on international voyages[3]. AIS density maps from different sources are presented in this section: data provided by the Croatian Ministry of The Sea, Transport and Infrastructure (MMPI, in Sect.3.1); data from EMODnet (in Sect.3.2); data from WWF (in Sect.3.3).

3.1 MMPI

MMPI provided AIS density maps for the 4 main RoPax vessels operating between Italy and Croatia, that represent time-averages for the period January to August 2019.

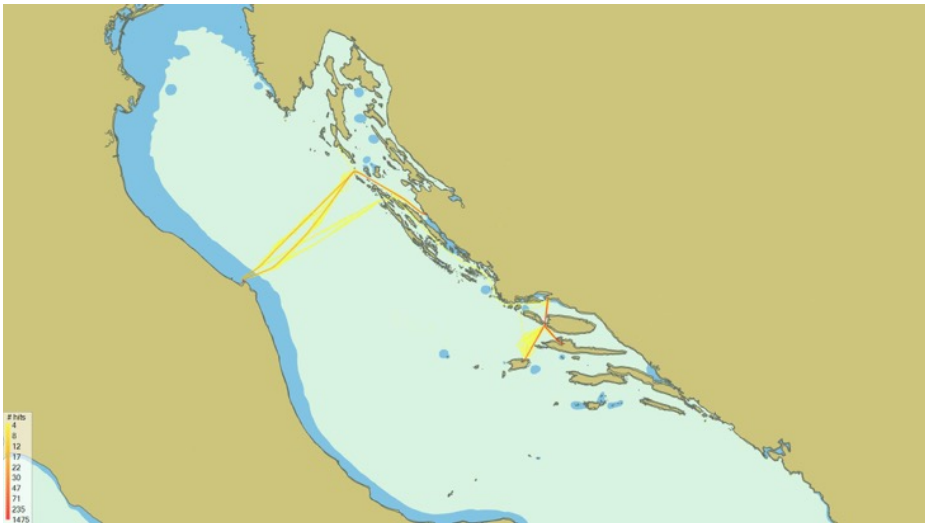

Figure 2 AIS density map for the "Zadar" vessel, in the period: January-August 2019.

---

[3] http://www.imo.org/en/OurWork/Safety/Navigation/Pages/AIS.aspx

The maps are shown in Fig.2-5.

It is seen that the „Zadar“ vessel (Fig.2) operates between Ancona and Zadar (with passages either North of Premuda or South of Molat). „Zadar“ also operates among Split, Stari Grad, and Vis.

„Marko Polo“ vessel (Fig.3) operates between Ancona and the Split area (Split city port, Stari Grad, and Vis). While the most frequent route is the straight line from Ancona to Split, other options include heading first towards the group of islands in front of Zadar and, once the Croatian shore is in sight, to Split.

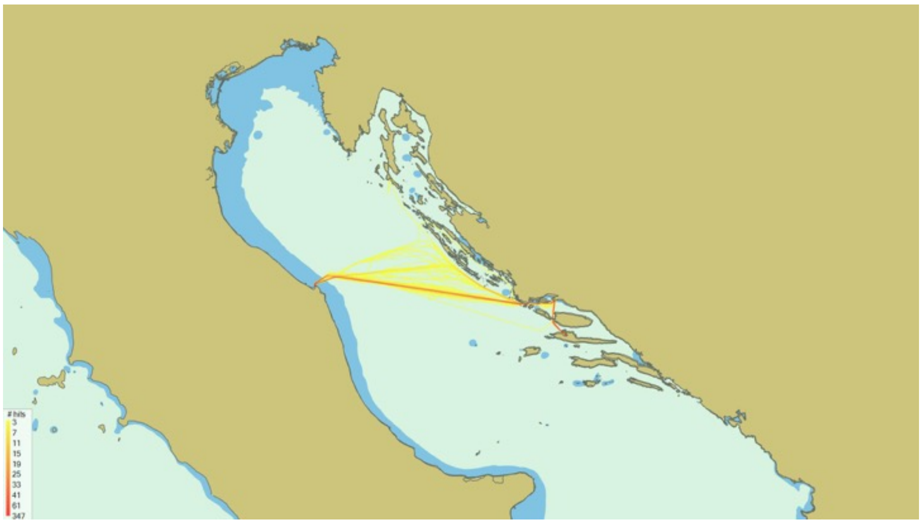

Figure 3 AIS density map for "Marko Polo" vessel, in the period: January-August 2019.

The „Aurelia“ vessel (Fig.4) operates between Ancona and the Split city port. The AIS system also registered at least one track from Ancona exiting the Adriatic Sea without calling at other Italian or Croatian ports.

Figure 4 AIS density map for the "Aurelia" vessel, in the period: January-August 2019.

Finally, the „Dubrovnik“ vessel (Fig.5) operates mainly between Bari and Dubrovnik and between Bari and Bar (Montenegro). An optional route is between Ancona and Split. Furthermore, at least one voyage from Dubrovnik to some shipyard in the Istria region left its footprint on this map.

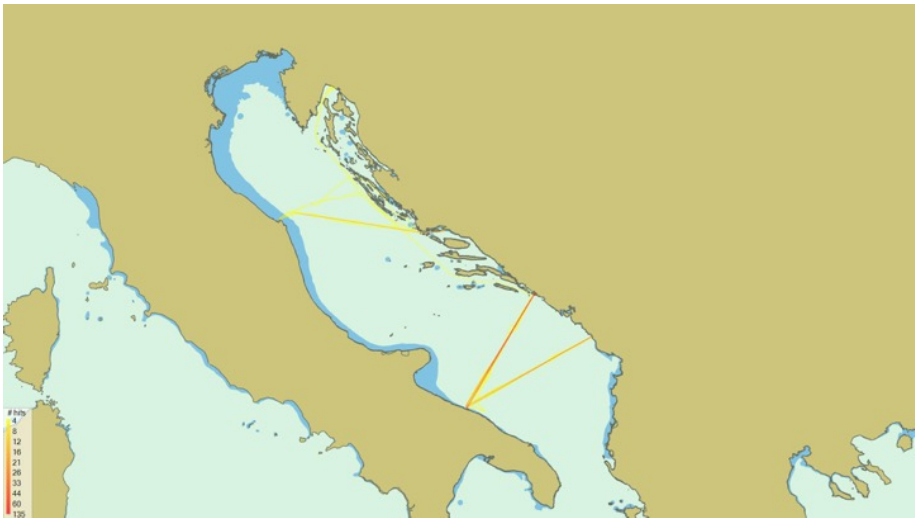

Figure 5 AIS density map for the "Dubrovnik" vessel, in the period: January-August 2019.

3.2 EMODnet

The EMODnet Human Activities portal[4] is being developed in the framework of the European Marine Observation and Data Network (EMODnet) as initiated by the European Commission. It aims to facilitate access to existing marine data on activities carried out in EU waters, by building a single entry point for geographic information on more than 14 different themes [EMODnet, 2019].

Among such themes, the „Shipping density“ theme provides AIS vessel density maps computed through two different algorithms (by either EMODnet or EMSA). Both EMODnet and EMSA data are organized by vessel class and the RoPax vessels are likely part of the „Passenger“ class. However, this class may also include cruise ships, catamarans, and similar vessels.

The EMODnet algorithm[5] provides the mean occupation time of each grid cell (hours per square km per month) while the EMSA's one provides the mean number of passages in each grid cell (route per square km per month). Thus, the EMSA algorithm tends to overestimate the signature of fast sailing vessels. The EMODnet data are available for both 2017 and 2018 (both as monthly and annual averages), while the EMSA data are available for 2019 only (both as monthly averages and „total“). Fig.6 displays the EMODnet maps for August of either 2017 or 2018 while Fig.7 the EMSA map for August 2019.

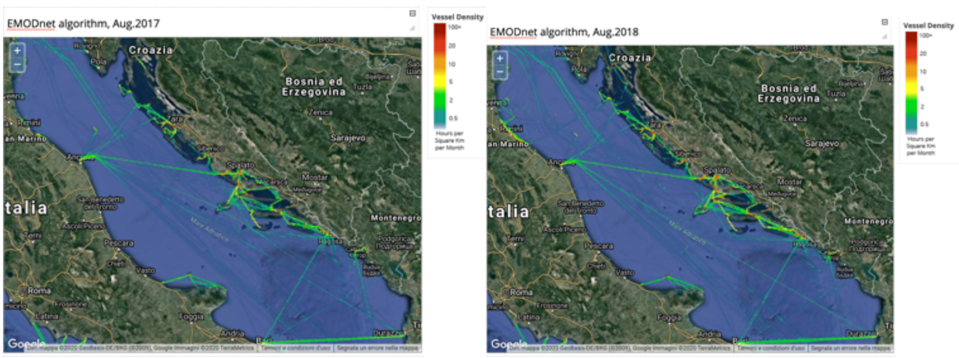

Figura 6 EMODnet AIS density map for August 2017 (left panel) or 2018 (right panel).

[4] https://www.emodnet-humanactivities.eu/

[5] https://www.emodnet-humanactivities.eu/documents/Vessel%20density%20maps_method_v1.5.pdf

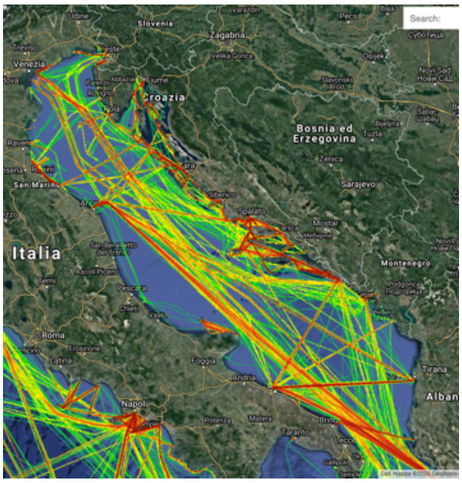

Figura 7 EMSA AIS density map for August 2019.

As expected from the different definition of route density in the two algorithms, the EMODnet maps better capture the coastal part (where the vessels tend to spend a larger amount of time per grid cell) than the open-sea part of the navigation. However, both in EMODnet and EMSA maps, the signal relative to RoPax is mixed up with the one relative to cruise ships, e.g. the Ancona-Durrës or Venice-Bari routes can be easily recognized.

3.3 WWF

The MedTrends project (Adriatic sub-region) performed an assessment of transnational marine economic growth in Adriatic-EU Member States to assess the capacity of the area to face future environmental pressures and conflicts between economic sectors. The project combined the collection and analysis of geo-localised socio-economic and environmental information on 8 key maritime sectors with a wider spatial analysis aiming to identify interactions between the sectors and potential effects on the marine and coastal environment [WWF-Mediterranean, 2016]. The Medtrends final report includes density maps provided by the Navama company for both freight and passenger traffic (Fig.8). They look more similar to the EMSA maps (Fig.7) than the EMODnet ones (Fig.6). In fact, the WWF algorithm does not make any reference to vessel speed [WWF-Mediterranean, 2016; p.18].

The main RoPax connections as in MMPI (Sect.3.1) and EMODnet human activities (Sect.3.2) data can be recognized, along with the cruise lines. Thus, a conclusion for Sect.3 is that all data sources considered agree that the Italy-Croatia RoPax traffic consists in the routes sailed by the 4 vessels of Sect.3.1

(Aurelia, Marko Polo, Zadar, Dubrovnik) and that this picture has been stable at least for the last 6 or 7 years.

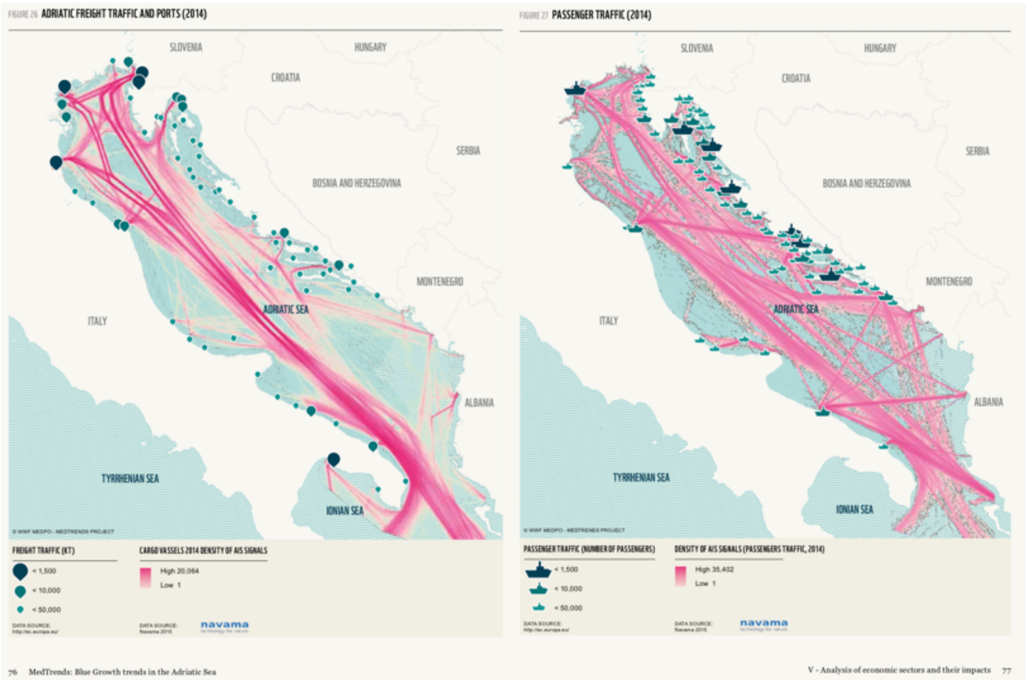

Figura 8 WWF average density maps for year 2014: freights (left panel) and passenger (right panel).

4. Connectivity gap analysis

After understanding the past and present picture of Adriatic Sea RoPax connection pattern, this last section of the report provides a contribution to the assessment of the needs for the future traffic pattern development.

The more general framework into which this problem could be cast is the Marine Spatial Planning (MSP) process. MSP brings together multiple users of the ocean – including energy, industry, government, conservation and recreation – to make informed and coordinated decisions about how to use marine resources sustainably[6]. In fact, there are many and concurrent drivers of development in the Adriatic region that could be taken into consideration. The already cited MedTrends report [WWF-

[6] https://en.wikipedia.org/wiki/Marine_spatial_planning

Mediterranean, 2016] provided an exemplary overview of the economic sectors[7] involved, their growth trend, and their mutual interactions and conflicts. Port Collaborative Decision Making (PortCDM[8]) could be another relevant framework to pursue a rational (re)allocation of vessel calls in view of efficiency.

The Italy-Croatia Interreg Programme is framed into the context of European strategies such as: Europe 2020, South-East Europe 2020, the Air Quality Directive 2008/50/EC and the Gothenburg Protocol (1999), and is committed to take care of natural habitats and Natura 2000 sites potentially impacted by the Programme actions. The GUTTA project has a specific focus on decarbonization of CB maritime transport. All this leads us to give priority to the environmental impact of the ferry routes in terms of CO2 emissions, for their contribution to anthropogenic climate change.

Therefore, our objective is to assess where is - if any – the connectivity gap for cross-border RoPax route between Italy and Croatia, with a focus on reachability of destinations (represented through the travel times) and environmental impact (in terms of CO2 emissions).

We are aware of the huge reduction of complexity implicit with such an approach. In particular, by focusing on travel times only, it neglects the full picture about freight and passenger flows in the region. As a minimum, the CIMIS data analysed in Sect.2 (maritime legs of the CB routes) should be complemented with information about flows along the terrestrial legs. In fact, the bare topological aspects of Fig.1 should be weighted with the actual in- and out-coming flows at the nodes of the traffic network. A more refined analysis may make use of flights data too. This information about terrestrial flows is not yet available to the GUTTA partnership though.

In the remainder of the GUTTA project, collection of feedback by the relevant stakeholders in the Adriatic region may contribute to fill some of this methodological gap.

In the following, the first subsection analyzes the situation of the so called “Northern Adriatic arc”, where RoPax transportation is not available (Sect.4.1), and then addresses the “oblique” connections between the South-Western and the North-Eastern edge of the basin (Sect.4.2.).

4.1 Northern Adriatic arc

A first RoPax connectivity gap is noted in the so called “Northern Adriatic Arc”: the harbours located along the coasts of Emilia-Romagna, Veneto, Friuli Venezia Giulia in Italy and Istria in Croatia.

[7] Oil & gas, Maritime transport & ports, Fisheries, Marine aquaculture,Tourism, Renewable energy, Marine mining, Military activities.

[8] https://cdn.website-editor.net/9f2b881c9552427daa829a899363c98d/files/uploaded/Port%2520CDM.pdf

In fact, several passenger-only ferry services, e.g. between Venice and several locations in Istria, are operational. However, there is no RoPax lines joining seaports north of Ancona on the West and Zadar on the East (cf. Fig.6). These routes compete with terrestrial connections of similar duration (cf. Tab.8) and likely for this reason do not offer also the vehicle transportation service.

Even southern maritime routes, such as Ancona-Zadar or Ancona-Split could suffer from the competition with terrestrial routes. However, in the latter cases the possibility to sail overnight provides a structural advantage for the maritime connections, and so the RoPax traffic finds its economical sustainability.

Table 8. Comparison of routes in the Adriatic arc by different transportation means.

	Trip duration		
	via **Car**	via **Ferry**	
Information source	GoogleMaps	croatiaferries.com	
			Cars admitted?
Venice-Pula	3h 16m	3h 15m – 3h 30m	No
Ancona-Zadar	9h 02m	6h 00m – 7h 30m	Yes
Ancona- Split	10h 08m	10h 15m – 11h 30m	Yes

4.2 Oblique routes

In the central and southern Adriatic Sea, being far from the Northern terrestrial arc between the Western and Eastern side of the basin, the strategic advantage of RoPax connection is even clearer than for the Northern arc routes.

In the following, we focus on voyages between Bari, the biggest city of the Adriatic (more than 320 000 inhabitants), and Zadar, perhaps the oldest continuously inhabited Croatian city. This route is called "oblique" (actually the direct route would head to about 330 deg) in the sense that is along the transversal axis of the basin, as instead the existing ones approximately are.

These voyages can be executed by combining a maritime passage with either one or two terrestrial legs. We consider in our analysis all possible present-day choices (there are 3) and also add a direct itinerary between the seaports of Bari and Zadar. This is done also in view of a possible low-carbon ferry service making use of the LNG import terminal under construction in the island of Krk[9] (through which ferries at

[9] https://www.lng.hr/en/

Zadar's harbour could be served via an electric bunkering barge) and plans for a similar facility at the harbour of Bari[10].

The LNG terminals are only an additional the reasons why we believe that this route could be appealing to the shipowners. LNG as a fuel for vessels is considered as a bunkering solution for reducing the greenhouse gases emissions and contributing to meet IMO decarbonization goals, as stated in MEPC.304(72). Also, when burned LNG emits considerably less SOx and NOx than heavy fuel oil, helping in matching the IMO 2020 sulphur cap. However, LNG mainly consists of methane, and methane slip (i.e., emissions of unburned methane) is of environmental concern, given that the unit greenhouse potential of methane is nearly 30 times larger than CO2's one. This, together with the fact that a LNG supply chain is not yet comparable to the oil one, has raised criticism about the potential of LNG as a sustainable green fuel (cf. Marine Professional, Sept/Oct 2019). Hydrogen is then proposed as a new fuel candidate. As we write this report, the discussion is still ongoing and the industry has not yet found a clear development direction.

Furthermore, for each itinerary, different options arising from the combination of different terrestrial and maritime vehicles are considered.

4.2.1 Methodology

The following list of hypotheses is made:

H1. Two vessels only are considered: Aurelia (SNAV) and Marko Polo (Jadrolinija), as they were found to carry most of the traffic in the Adriatic (Tab.4-7) and are representative of two quite different emission intensity (EI) levels. EI values, defined as CO2 emissions per unit transport work, are obtained from the annual average values provided by the European THETIS-MRV dataset[11] published by EMSA and are reported in Tab.9.

- *Table 9 Parameters for the RoPax vessels considered in the analysis*

IMO	vessel	Emissions Intensity (EI)	
		gCO2/(pax*nmi)	gCO2/(t*nmi)
7602120	Aurelia	767.7	83.43
7230599	Marko Polo	4.9	2.35

[10] https://superlng.adrioninterreg.eu/
[11] 2018-v147-31012020-EU MRV Publication of information.xlsx downloaded from https://mrv.emsa.europa.eu/#public/emission-report

H2. Three types of road vehicles are considered for freight transportation: a car, a van (light-duty vehicle) and a truck (heavy- duty vehicle). For both car and van, EU average values are taken (see footontes in Tab.10). For trucks, there currently is a European monitoring gap with respect to the corresponding US legislation[12]. The first ever European normative for monitoring and curbing trucks emissions has only recently (April 2019) been approved[13]. Therefore, the trucks values are based on some educated manipulation of US data and should be considered as preliminary estimations only.

- *Table 10 Parameters for the terrestrial vehicles considered in the analysis*

Vehicle	Main function	Weight (M)	Specific Emissions (SE)	Total emissions
		t	gCO2/km	kg
car	passenger	1.4	122[14]	-
van	light-duty	3.5	158[15]	-
truck	heavy-duty	15.9	372[16]	-
Coach		18	70[17]	-
Train	Emissions for the whole BA-AN leg			21.1[18]

H3. Two types of road vehicles are considered for passenger transportation: train and coach. Coastal railways are available on the western side of the Adriatic Sea and a coach is needed on the eastern side for moving without making use of a private transportation means. Related CO2 emission parameters are reported in Tab.10.

H4. Four itineraries between Bari and Zadar as in Tab.11 are considered

H5. Terrestrial distances are taken from GoogleMaps

H6. Maritime distances are taken along straight lines between seaports[19]

H7. Travel times for road vehicles are taken from GoogleMaps. For the van, they are increased by a 10% factor; for the truck, by 20%, for the coach, they are taken from the official schedule times[20]

[12] https://www.transportenvironment.org/publications/europe%E2%80%99s-lost-decade-truck-fuel-economy

[13] https://www.europarl.europa.eu/news/en/press-room/20190412IPR39009/meps-approve-new-co2-emissions-limits-for-trucks

[14] https://www.eea.europa.eu/highlights/average-co2-emissions-from-new

[15] https://ec.europa.eu/clima/policies/transport/vehicles/vans_en

[16] https://www.bts.gov/content/single-unit-2-axle-6-tire-or-more-truck-fuel-consumption-and-travel

[17] https://www.delijn.be/en/overdelijn/organisatie/zorgzaam-ondernemen/milieu/co2-uitstoot-voertuigen.html

[18] http://ecopassenger.hafas.de/hafas-res/download/Ecopassenger_Methodology_Data.pdf

[19] https://sea-distances.org/

[20] https://www.buscroatia.com/

H8. Travel times for train and ferries are taken from the official schedules and, if more than one duration is provided on different days of the year, the shorter one is here used

H9. Travel times for the new itinerary are computed by rescaling travel times for the Ancona-Split voyage (the longest maritime leg available so far available in the Adriatic) by the length ratio of the two itineraries

H10. The CO2 emissions per vehicle along each itinerary are computed through the formula:

$$\mathrm{CO}_2 = \sum_{j \in \mathrm{legs}} d_j \cdot \mathrm{SE}_j^{(v,s)}$$

where the specific emissions SE along journey leg *j* for terrestrial vehicles are given in Tab.10, while for maritime legs via vessel *s* and vehicle *v* they are computed as:

$$\mathrm{SE}_j^{(v,s)} = \mathrm{EI}^{(s_j)} \cdot \mathrm{M}^{(v_j)}$$

with the vessel emission intensities EI from Tab.9 and the vehicle weights M from Tab. 10. For the train leg, the SE is taken from the reference quoted in Tab.10

H11. It is assumed that there are no waiting times for embarking/disembarking operations and customs or border policy formalities

H12. Calm sea conditions and no road congestion are assumed (see Conclusions for how to remove this hypothesis).

Table 11 Itineraries considered in the analysis.The transportations means used in each leg are given in brakets. For terrestrial legs (such as Bari-Ancona), the two alternatives refer to the case of freight/passenger transportation.

#	Name	Leg 1	Leg 2	Leg 3
1	BA-AN-ZD	Bari-Ancona (highway/ train)	Ancona-Zadar (RoPax)	-
2	BA-DU-ZD	Bari-Dubrovnik (RoPax)	Dubrovnik-Zadar (highway/ coach)	-
3	BA-AN-SP-ZD	Bari-Ancona (highway/ train)	Ancona-Split (RoPax)	Split-Zadar (highway/ coach)
4	BA-ZD	Bari-Zadar (RoPax)	-	-

4.2.2 Results

For each itinerary of Tab.11, the total duration and the total CO_2 emissions per vehicle are computed. They are displayed in a duration-emission plane in Fig.9 for freight and in Fig.10 for passenger transportation and are discussed separately in the following paragraphs.

In order to appreciate the involved amounts of CO_2 emissions, following data are here recalled:

- Daily we breathe about 0.9 kg of CO_2 per adult per year [DeLijn]
- 1 hectare of woodland (in our climate) absorbs around 27.5 kg of CO_2 /day [DeLijn]
- The annual pro-capita CO_2 emissions in Italy were 7.2 tonnes in 2016 [MEF 2019]

Furthermore, the data relative to emission per vehicle shown in Fig.9 can be rescaled for accounting for the actual number of vehicles transported, which is on the order of tens per voyage, as resulting from Tab.4 and 5. Similarly, the data relative to emission per passenger shown in Fig.10 can be rescaled for accounting for the actual number of passengers transported, which is on the order of hundreds per voyage, as resulting from Tab.6 and 7.

4.2.2.1 Freight

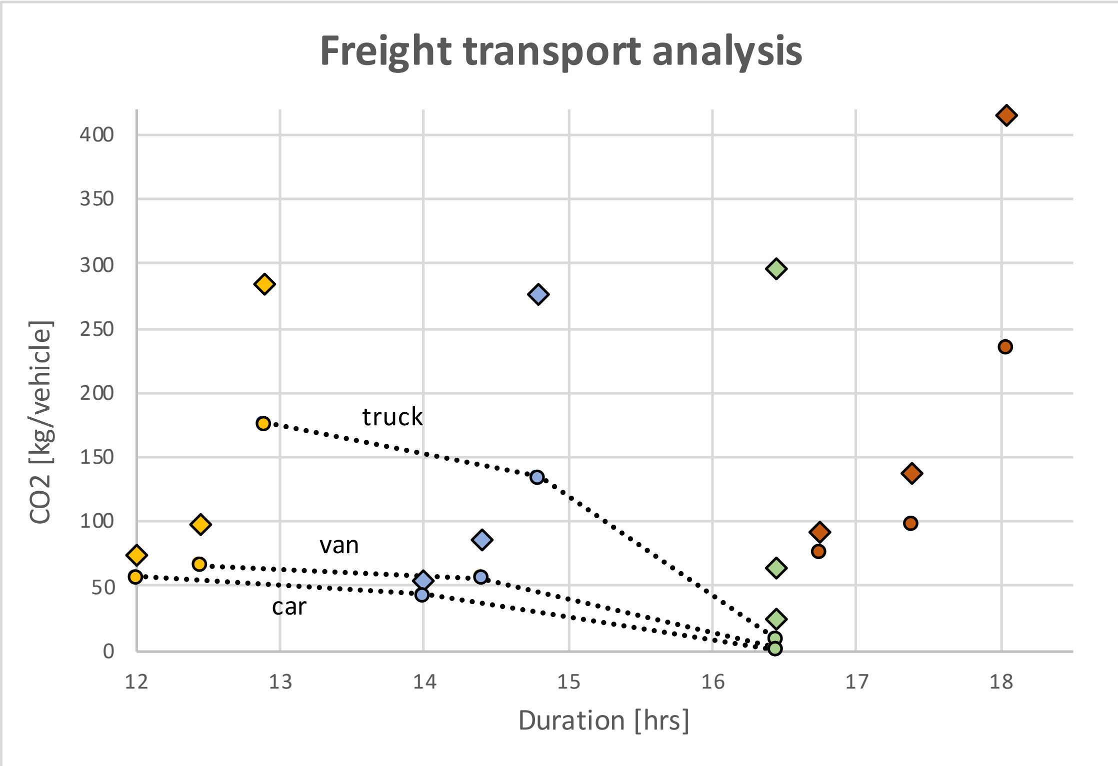

Figure 9 Multiobjective analysis of the itineraries (with colors) of Tab.11 for freight transportation. The marker type refer to either Aurelia (diamonds) or Marko Polo (circles) vessel. Due to hypothesis H7, for a given symbol and color, the car/van/truck results are displaced horizontally. The Pareto frontier of each vehicle type is given by a dashed line. Parameters used in the computations are given in Tab.9-10.

For freight transportation, there is a significant spread both in CO2 emissions and duration. The spread is mainly generated by the different vessel and vehicle emission intensities (Tab.9-10), and also by the different length of the terrestrial and maritime legs.

For a given vehicle type, the BA-AN-SP-ZD leads to both largest travel times and emissions per vehicle. This is due to the much longer terrestrial part of the journey (a total of 621 km, including the legs on both Italian and Croatian side).

The Pareto-efficient[21] itineraries for each vehicle type are also shown in Fig.9. These solutions have the property that their duration cannot be decreased without increasing the CO_2 emissions. For no vehicle type considered the BA-AN-SP-ZD itinerary results to be Pareto-efficient.

The suggested direct itinerary BA-ZD requires a travel time about 5 hours longer than along BA-AN-ZD but still shorter than BA-AN-SP-ZD. As seen from Tab.12, the direct itinerary leads to quite significant CO_2 savings per vehicle. The savings are especially significant if an energy efficient vessel (Marko Polo) is employed.

Table 12 Emission changes (% CO2 emissions/vehicle) of the proposed BA-ZD itinerary with respect to the existing 3 itineraries for the various combinations of vessel/vehicle.

vessel	vehicle	BA-AN-ZD	BA-DU-ZD	BA-AN-SP-ZD
Aurelia	truck	3.9	7.2	-28.8
Aurelia	van	-33.7	-25.5	-53.1
Aurelia	car	-65	-53.1	-71.7
Marko Polo	truck	-95.3	-93.8	-96.5
Marko Polo	van	-97.2	-96.7	-98.2
Marko Polo	car	-98.7	-98.3	-99.0

[21] https://en.wikipedia.org/wiki/Pareto_efficiency

4.2.2.2. Passenger

For passenger transportation (Fig.10), the unit CO_2 emissions are roughly halved with respect to the corresponding emissions for freight.

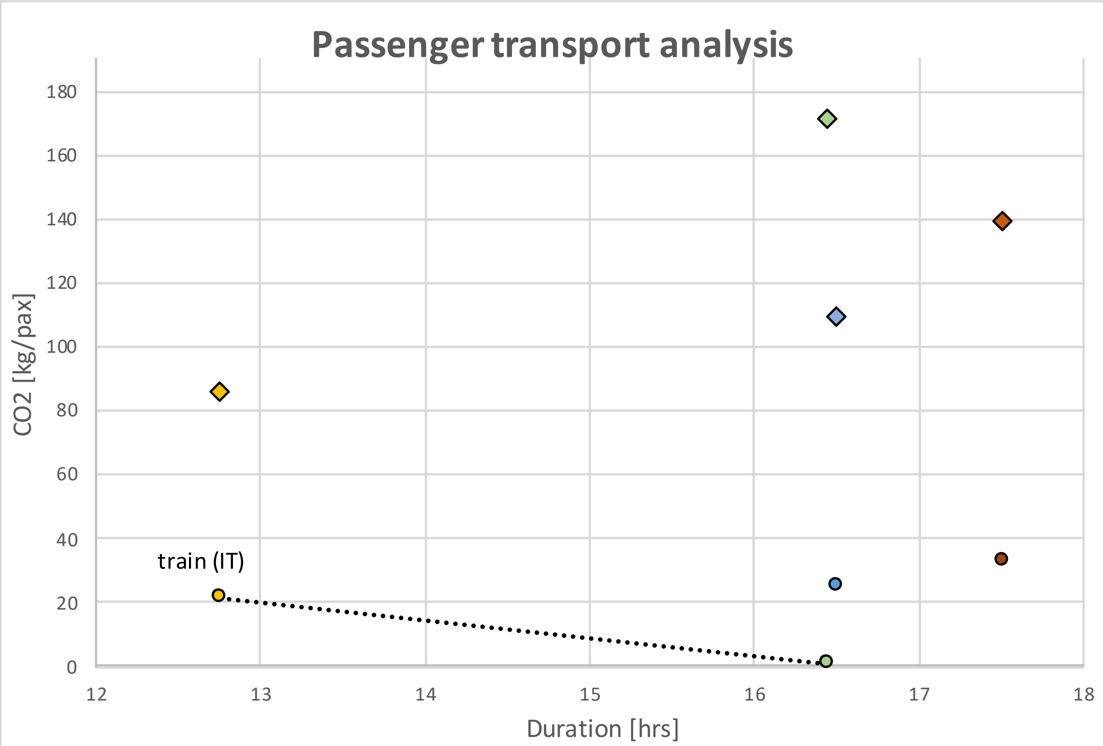

Figure 10 Multiobjective analysis of the itineraries (with colors) of Tab.11 for passenger transportation. The marker type refer to either Aurelia (diamonds) or Marko Polo (circles) vessel. The Pareto frontier is given by a dashed line. Parameters used in the computations are given in Tab.9-10.

However, in this case neither the BA-DU-ZD nor the BA-AN-SP-ZD include Pareto-efficient itineraries. This is due to the fact that the solutions including any terrestrial legs in Croatia are highly unfavoured in terms of CO_2 emissions, given the fact that railways are available in Italy (Fig.1) and allow for quite low emissions per unit distance compared to the coach-based transportation.

On the direct BA-ZD route, the CO_2 emissions per passenger are reduced only if an energy-efficient vessel such as Marko Polo is employed (cf. Tab.13). If instead Aurelia is employed, emissions will increase.

Table 13 Emission changes (% CO2 emissions/passenger) of the propsed BA-ZD itinerary with respect to the existing 3 itineraries for the two vessels.

vessel	vehicle	BA-AN-ZD	BA-DU-ZD	BA-AN-SP-ZD
Aurelia	Train/coach	100	57.1	23.3
Marko Polo	Train/coach	-94.9	-95.6	-96.7

5. Conclusions

An objective assessment of Adriatic Sea RoPax connectivity and its potential for a greener transformation has been performed. The analysis was based on various data sources, including: CIMIS port records, AIS density maps, the EU-MRV dataset maintained by EMSA, among others.

The present-day topology of Adriatic Sea connections shows the prominent role of the Split-area harbour system for both freight and passenger transportation. There is an evidence that this role has been stable for most of the past decade.

Oblique (i.e. not along the transversal axis of the basin) connections instead are not yet available. This comes along with the fact that coastal railway connections are well developed on western side of the Adriatic only. A practical consequence is that territories in the South West (Puglia, Molise) are not easily linked to those in the North East (Istria and northern Dalmatia in general) of the basin.

The impact of this lack on CO_2 emissions for both freight and passenger transportation is assessed. Multiple itineraries linking Bari to Zadar (or viceversa) are considered, with inclusion of a direct maritime link between the two harbour cities. A Pareto-efficiency analysis demonstrates that, for both freight and passenger transportation, the new itinerary would outperform the existing ones at the cost of a limited lengthening in the journey duration. An energy vessel efficient would be required for the case of passenger transportation, while the freight transportation would be Pareto-efficient for any of the vessels considered.

This work is based on three main steps: ignoring the flows and focusing on the topology of the CB connections; assessing the impact of a specific route (from Bari to Zadar) along several itineraries; making assumptions about several computational aspects, as listed in Sect.4.2.1.

The last assumption (H12) correponds to the hypothesis of constantly calm sea. It will be removed in the frame of the GUTTA project, through a further development of the VISIR[22] ship routing model for using meteo-oceanographic forecast fields in the Adriatic for computing time- and emission-efficient routes.

Bibliography

Beran et al [2019] "Correlation Analysis Of Maritime Traffic", in NAŠE MORE 2019, 1st International Conference of Maritime Science & Technology, Dubrovnik, Croatia 17 – 18 October 2019, http://www.nasemore.com/conference/

[DeLijn] https://www.delijn.be/en/overdelijn/organisatie/zorgzaam-ondernemen/milieu/co2-uitstoot-voertuigen.html

[MEF 2019], http://www.dt.tesoro.it/modules/documenti_it/analisi_progammazione/documenti_programmatici/def_2019/Allegato_-_BES.pdf

WWF-Mediterranean [2016], http://www.medtrends.org/reports/MedTrends_AD-Report.pdf

EMODnet human activities [2018], https://www.emodnet-humanactivities.eu/view-data.php

EMSA THETIS-MRV [2019], https://mrv.emsa.europa.eu/#public/emission-report

UNCTAD [2019], https://unctad.org/en/PublicationsLibrary/rmt2019_en.pdf

[22] http://www.visir-model.net/