Supplementary material for the article

To pollute or not to pollute? Exploring MARPOL efficiency in the Adriatic Sea

---

1. Brief preliminaries

1.1. The Adriatic Sea and its sailing routes

The Adriatic Sea is a semi-enclosed sea of the Mediterranean with size equal to 138595 km^2 and a total of 7911 kilometres of coasts, out of which 3737 kilometres make mainland coast, while 4174 kilometres refer to island coast (Lušić and Kos, 2006). Three quarters of the mainland coast belongs to Croatia (1777 km) and Italy (1000 km), while the remaining quarter is located in Albania (472 km), Montenegro (200 km), Slovenia (47 km) and Bosnia and Herzegovina (20 km). The Adriatic Sea is a rather shallow sea with average depth of 173 metres. It exchanges the waters with the Mediterranean through the Otranto Strait with the rate of 1-5 years (Morović et al., 2016).

The biggest ports in the Adriatic Sea are located on its north-western coast and most of the traffic in the Adriatic occurs on the sailing routes that connect these ports to the Mediterranean (Komadina et al., 2013). Several ports in Italy (Venezia, Trieste), Croatia (Rijeka, Omišalj, Ploče), Slovenia (Koper), Montenegro (Bar) and Albania (Vlore) serve as terminals for tankers, which puts the longitudinal sailing routes at higher risks to eventual pollution (Lušić et al., 2017). While emphasising that one large oil spill accident in the Adriatic Sea could put down economies of surrounding coastal countries, Morović et al. (2016, p. 153) find (among others) that (1) most of the oil spills are located along the main (longitudinal) shipping routes, (2) most of the oil spills are released during night time, and detected during descending (morning) satellite passes, and that (3) significant spills can be a sign of routine tank washing operations or illegal discharges.

1.2. Maritime transportation in the Adriatic Sea

According to the UNCTAD and Eurostat statistics most of the ship arrivals in the Adriatic in 2018 occurred in Italy and Croatia, almost 95 thousand and more than 68 thousand (out of the total 167 thousand arrivals), respectively.[1] However, the largest and newest vessels are exhibited in the Slovenian port of Koper where a ship of size above 30 thousand gross tonnage (GT)[2] is on average 14 years old.

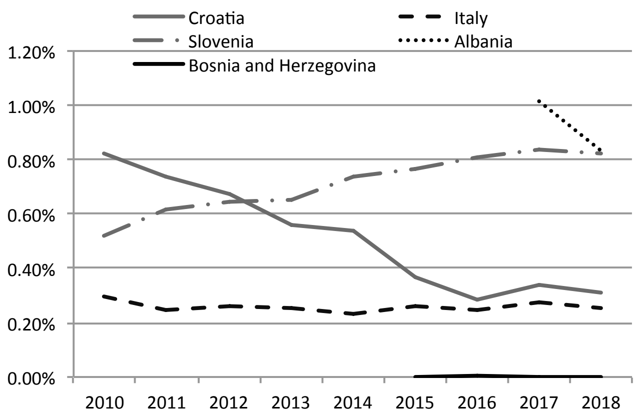
[1] Worth mentioning is that the UNCTAD statistics shows the port arrivals for Italy standing at almost 230 thousand. But, in case only Italian ports on the Adriatic Sea are considered, then approximately 41.3% of all gross weight were transported to and from these main points, while the remaining 58.7% to and from ports on the Ionian and Tyrrhenian sea.

[2] Gross tonnage (GT) is a volumetric measurement of the enclosed space in a ship. It is not related with weight and uses gross tons as units. Most of the UNCTAD and EUROSTAT statistics are in GT. However, it should be distinguished from deadweight tonnage (DWT) which measures the weight in metric tonnes (1000 kg) of cargo, fuel and stores that will put the ship down to its loadline marks.

Moroever, according to Eurostat (2020) nine Adriatic ports in 2018 exhibit a record of vessels of more than 10 million GT. Among such ports are two Croatian ports (Ploče and Rijeka), six Italian ports (Ancona, Bari, Brindisi, Ravenna, Trieste and Venezia) and one Slovenian port (Koper). The highest GT value is evidenced for the port of Venezia (more than 85 million GT), followed by Trieste and Bari (more than 76 and 64 millions of GT, respectively). One the one hand, the highest amount of liquid bulk tankers (above 20 million GT) and container ships (above 27 million GT) arrives to Trieste, while most of the cargo ships are directed to or from Ancona and Bari (44 and 47 million GT, respectively). On the other hand, 499 cruise ships arrived in Venice in 2018. This number stands out compared to cruise ships registered in other main Adriatic ports, given that the remaining eight ports all together exhibit 488 cruise ships.

Figure 1 shows the economic relevance of the (sea) transport industry, measured by the share of sea transport revenues in GDP. In 2018, sea transport in Slovenia and Albania is mostly significant and accounts 0.83% of GDP. The same values for Croatia and Italy stand at 0.31 and 0.26 percent of GDP, respectively. However, the numbers for Italy do not extrapolate only the part of sea transport carried out in the Adriatic Sea. So, using the aforementioned fact that 41.3% of the total weight transported by sea to/from Italy relates to the Adriatic ports, we can approximate the relevance of the Adriatic Sea transport only. This simple calculation conveys that on average in the 2010-2018 period Adriatic Sea transport in Italy makes 0.11% of GDP or 4.3 million euro annually.

Figure 1: *Sea transport as % of GDP, 2010-2018*



Note: Data for Montenegro are unavailable. Data for Bosnia and Herzegovina are available only for one datapoint, i.e. the share of sea transport in GDP in 2016, which stands at 0.002%.
Source: Eurostat (2020).

1.3. Fisheries in the Adriatic

According to FAO (2018, p. 7) 12.3% of all the operating vessels in the Mediterranean and Black Sea are reported in the Adriatic region. Namely, in 2017 the number of registered fishing vessels of Adriatic countries stands at 18100 and with a total capacity of 186227 GT (Table 1). However, numbers related to Italy cover all the three seas (Adriatic, Ionian and Tyrrhenian).

Table 1: *Fishing fleet characteristics, 2017*

	Number of vessels	**Capacity (GT)**	**Average age**	**Landing (tonnes)**	**SSF % of total**
Albania	571	6955	43	6282	63%
Croatia	6042	34509	36	68815	90%
Italy	11255	143535	34	179409	70%
Montenegro	153	889	37	932	78%
Slovenia	79	339	39	128	87%

Notes: Data for Bosnia and Herzegovina stand at zero. Data for Italy cover the whole country, not only the ports on the Adriatic Sea. SSF - Small scale fisheries.
Source: FAO (2018, p. 5, 9 and 94).

Moroever, FAO (2018, p. 27-28) points out that on average in the 2014-2016 period the annual total landing in the Adriatic Sea amounts to 193500 tonnes, which are mainly dominated by Italy (54%) and Croatia (41%), followed by Albania (4%), Montenegro (0.5%) and Slovenia (0.1%). If this is related to the data in Table 1, then, for year 2017, it is possible to conclude that 90634 tonnes of landing can be attributed to Italy. The total amount of fish landing in the Adriatic Sea in 2017 is equivalent to almost 168 thousand tonnes with a total value estimated to 372 million EUR[3]. As shown in Table 2 the average landing value per tonne is highest in case of Slovenia (7204 EUR/t) and lowest in Croatia (715 EUR/t), while the average across the five Adriatic countries that own a fishing fleet stands at 3100 EUR/t.

Table 2: *Annual economic indicators of fish landing in the Adriatic Sea, 2017*

	Landing in tonnes	**Landing value in mil EUR**	**Landing value per tonne**	**Employment (persons)**	**Landing per employee in EUR**
AL	6282	21.201	3375	971	21834
HR	68815	49.223	715	7227	6811
IT	90634	269.656	2975	8593	31381
ME	932	1.167	1252	133	8776
SI	128	0.922	7204	110	8383

Notes: Data for Bosnia and Herzegovina stand at zero. Data for Italy cover only the ports on the Adriatic Sea. AL - Albania, HR - Croatia, IT - Italy, ME - Montenegro, SI - Slovenia.
Source: FAO (2018) and authors' calculations.

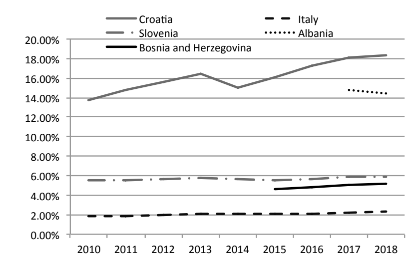
The fishing industry also provide for significant job opportunities. Employment onboard fishing vessels in the Adriatic Sea comprises 17034 persons, out of which the most (8593) on Italian fishing vessels. Worth mentioning is that the total number of employees onboard fishing vessels for Italy is 25861 (FAO, 2018), meaning that one third of it relates to the Adriatic Sea. Croatia counts 7227 employees on fishing vessels, while the remaining three countries stand below one thousand employees. The most efficient employees onboard fishing vessels seems to be the Italians and Albanians, given the average annual landing per employee in their case is 31381 euro and 21834 euro, respectively.

[3]To be precise, FAO (2018, p. 33) reports that the total landing value in the Adriatic Sea corresponds to 413.5 million USD. Given that all previous indicators, as well as forthcoming analysis in our case is expressed in euro, in Table 1 we convert USD values in euro using the mean exchange rate between the two currency during 2018, i.e. 0.9.

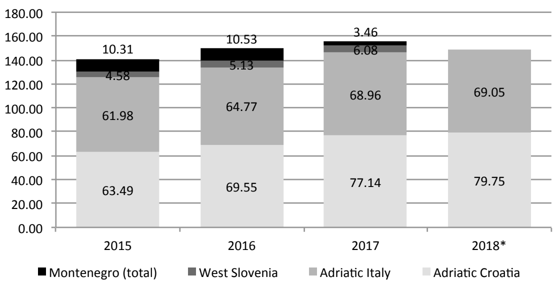
1.4. Tourism in the Adriatic

Travel and tourism is another relatively important service that substantially credits the balance of payment and creates substantial economic output. If data for tourism in the 2010-2018 period are considered, it is possible to note that the relative share of tourism in GDP has an increasing trend in Croatia, while in case of other countries it remains stable and constant (Figure 2a). Worth mentioning is that Croatia makes out of tourism on average more than 7.4 billion EUR annually, which is equivalent to 70% of all the services' credits recorded in the balance of payment, and to almost 20% of its GDP. Thus, tourism is quite significant for the Croatian economy.

Figure 2: *Economic output of travel/tourism and number of nights as one of the main indicator in tourism*



(a) *Tourism as % GDP*



(b) *Number of nights spent at tourist accommodations, in mil.*

Note: Data for Montenegro, left panel are unavailable. Data for Montenegro and West Slovenia for 2018, right panel, are unavailable. Data for Italy cover the whole country.
Source: Eurostat (2020).

For the purpose of this paper's analysis two additional facts are relevant. First, regarding the relative importance of tourism in % of GDP, Eurostat (2020) does not report values for Montenegro. Therefore we refer to Andričević et al. (2011), which show how tourism in Montenegro amounts to 17% of GDP in 2011. Second, the tourism data for all countries are not restricted to the Adriatic region and tourism as percent of GDP is not reported on regional basis. Therefore, to get the monetarized values of travel that relate to the Adriatic Sea, we use the number of nights spent at touristic accommodation establishments (Figure 2b) as proxies. Although available at a regional level, we are aware that the number of nights does not restrict to coast cities and municipalities. So,we assume that most of the tourist that visit regions that have shorelines on the Adriatic Sea visit also the seaside during their staying. With that assumption in mind it is possible to point out that in case of Croatia on average (2010-2018 period) more than 96% of the nights were registered in the Adriatic region (coastal Croatia). The same share for Italy is much lower and stands at 32% on average. In particular, number of nights registered in the Italian's regions Veneto, Friuli-Venezia Giulia, Emilia Romagna, March, Abruzzo, Molise and Puglia make one third of the total number of nights registered in Italy. In case of Slovenia, the European regional statistics differentiate between east and west Slovenia. West Slovenia makes more than 71% of all nights spent at different tourist accommodations.

1.5. Ecosystem and environment of the Adriatic Sea

The increasing exploitation of marine resources, the use and degradation of habitats and the diversification of pollution represent serious threats to the future of the Mediterranean and Black Sea environments (FAO, 2018, p. 69). Moreover, UNEP/MAP-Plan Bleu (2009, p. 69) emphasises that there are about 200 large oil tankers navigating in the Mediterranean Sea daily posing additional threat to marine life in the Mediterranean, along with the growth of harmful algae blooms or biological invasions of species. Both of the latter accelerate and decline native species, already under environmental stress, leading to higher risks of their extinctions. The European Environment Agency carefully monitors the European marine ecosystem. This includes screening the trends in the introduction of marine non-indigenous species to European seas (Adriatic Sea included) along with their growth, inspecting hazardous substances in marine organisms, tracking the status of fish and shellfish stocks, and monitoring marine protected areas. All of these are very relevant for the the discussion of the ecosystem status, but their are difficult (if not impossible) to monetarize. Therefore, we focus and rely on the most relevant ruiner of the marine environment, i.e. plastic pollution. Beaumont et al. (2019) show that all ecosystem services are impacted to some extent by the presence of marine plastic[4] and postulate a 1-5% reduction in ecosystem service delivery as a result of the stock of marine plastic in 2011. This 1-5% decline equates to an annual loss of 500-2500 billion USD.

2. Estimation of marginal private costs

To calculate the daily pollution costs per type of vessel we borrow from the work of Carić (2010), that details on pollution costs of cruise ships solely. According to Carić (2010, p. 169) the daily pollution quantities per person per day (on a cruise ship with approximately 3000-3500 passengers) are as shown in Table 3.

Table 3: *Daily waste quantities per person and per ship for a cruise ship*

Environmental indicator	Per person (passenger)	Per cruise ship
Solid waste	4 kg	10.5-12 t
Air pollution CO_2	0.40 kg/km	1203 kg/km
Black waters	40 l	60000-120000 l
Grey waters	340 l	1.02 mil l
Bilge waters	10 l	30000 l
Hazardous waste	0.16 kg	390-480 kg

Source: Carić (2010, p. 169)

Our analysis, besides cruise ships, includes five more types of ships: small, medium and large oil tankers, fishing vessels and ro-ro passenger ships. These types of ships make most of the traffic in the Adriatic Sea and their two main technical characteristics are shown in Table 4

In order to quantify the amounts of waste across different ship types as done for cruise ships in Table 3, we implement the following strategy. We use annual data about black, grey, bilge and oily waters shown in Golam Zakaria et al. (2017), assuming that the amount of waste created is

[4]Refer to references therein for a deeper discussion of all of the facets of marine plastic pollution.

Table 4: *Description of ship types included in the analysis (except cruise ship)*

Type	**Capacity** (1 mt = 1000 kg)	**Crew in persons**
Small tanker	up to 1000 mt	12
Medium tanker	from 1000 to 1750 mt	22
Large tanker	above 1750 mt	25
Fishing vessel	from 100 to 250 mt	6
Ro-ro passenger	250 mt	20

equal between inland water transportation and maritime transportation[5]. Then we accommodate the annual values to daily levels by dividing with 365 days. The daily waste rates per type of waste are used to access the pollution costs per type of vessel. Namely, when a vessel or ship is environmentally friendly it also bears all waste management costs indicated in Table 3. When in a port, a ship discharges the waste and pays the fees according to the type of waste.

Applied waste management fees vary across different countries Hogg (2002, among others). Having in mind the purpose of our paper and countries involved in the analysis, we often use the lowest fee applied or an average fee. This makes our estimates conservative and our analysis cautious. Moreover, it safeguards us from biased inflated pollution costs.

Solid waste management has highly differentiated costs across the set of our countries. For example, in Croatia solid waste management is delivered by the local government (cities and municipalities) and different rates apply, depending on the city or municipality into question. Nevertheless, Carić (2010) concludes that a typical rate on the coast is around 0.057 EUR/kg. According to Hogg (2002) for example, the same waste management in Italy is charged 0.15 EUR/kg. In order to keep our costs as conservative as possible we will use the lower Croatian fee of 0.057 EUR/kg of solid waste.

The treatment of black and grey waters also varies within countries. EEA (2005) points that these costs range between 180 and 800 euro per capita on the European ground, with an average of 490 euro paid annually. If that annual amount is broke into a daily amount and divided by the average daily consumption of water in Europe (i.e. 150 litres per day), it results in 0.00893 EUR/l. As noted by Carić (2010) the same cost in Croatia is more than three times lower and results in 0.00265 EUR/l. Again, to make the costs as conservative as possible, we apply the latter rate in our analysis.

Additionally, the treatment of oily bilge waters presents heterogeneous costs on the EU ground that can go up to 0.22 euro per litre. But, again, in order to be as conservative as possible, and not to inflate the pollution costs by no means, we adopt the same rate used for black and grey waters when assessing the total pollution costs per type of ship and vessel. Moreover, the continuous improvement in environmental requirements about oily wastewater treatment and used technology increases the level of efficiency, which goes in favour of reducing the costs.

As pointed by Hogg (2002), the costs of treatment of hazardous waste in Europe varies between 0.22 and 2.28 euro per kg, with an average standing at 1.53 euro per kg. The same costs in Croatia reach 3.36 euro per kg, which is more than double the EU average. Therefore, once again, we use the EU average value (Croatia's costs excluded), and prefer a cautious estimate of

[5]Golam Zakaria et al. (2017) show that, on a yearly level, a small, medium and large tanker create a total of waste waters of 50.2, 105.9 and 305 million kg per year, respectively.

the costs.

Air pollution costs are difficult to assess on a daily basis. Such costs relate to distance (usually kilometres) made by a vessel in a day. Given that data about average routes in kilometres per type of vessel are unavailable, we discard these costs from our analysis for all types of vessels except the cruise ship. To assess these we borrow from Transport and Environment (2019), according to which the main indicators per Adriatic countries are summarized in the following Table. The amounts of air pollution shown in Table 5 largely depend on sailing time, that is why the specific number of cruise ships cannot be directly linked to the amount of pollution they create.

Table 5: *Emissions from cruise ships in Adriatic ports, 2017*

	Number of cruise ships	**Sailing time**	SO_x **(in kg)**	NO_x **(in kg)**	PM **(in kg)**
Croatia	78	42324	3,589,093	6,373,174	558,084
Italy	81	73626	7,982,279	14,589,120	1,246,012
Slovenia	33	1228	13,471	55,800	2,484

Notes: Data for Croatia include cruise ships in ports Rijeka, Dubrovnik and Split. Data for Italy refer only to the Adriatic ports of Venezia and Bari.

Holland and Watkiss (2005) report for the European Commission DG Environment estimated marginal external costs of emissions at sea across different seas, among which the Northern Mediterranean. We use these estimated costs to assess the air pollution costs of cruise ships, which stand at 4700, 6200 and 10000 euro per tonne of pollution by SO_2, NO_x and PM, respectively. The latter with related figures shown in Table 5 allow us to estimate and set the average pollution costs per cruise ship per day (assuming they sail 365 days a year) at 933.70 euro per day of sailing.

References

Andričević, R., Meliadou, A., Miletić, M. and Kišević, M. (2011). *Adriatic Sea Environment Program: Rapid Assessment of Pollution Hotspots for the Adriatic Sea.* World Bank Final Report, October 2011.

Beaumont, N.J., Aanesen, M., Austen, M.C., Börger, T., Clark, J.R., Cole, M., Hooper, T., Lindeque, P.K., Pascoe C. and Wyles, K.J. (2019). *Global ecological, social and economic impacts of marine plastic.* Marine Pollution Bulletin, 142, pp. 189–195, doi:10.1016/j.marpolbul.2019.03.022.

Carić, H. (2010). *Direct pollution cost assessment of cruising tourism in the Croatian Adriatic.* Financial Theory and Practice, 34, 2, pp. 161–180.

Holland, M. and Watkiss, P. (2005). *Benefits Table database: Estimates of the marginal external costs of air pollution in Europe*, European Commission DG Environment, available at *https://ec.europa.eu/environment/enveco/air/pdf/betaec02a.pdf*.

Hogg, D. (2002). *Cost of municipal waste management in the EU. Final Report to DG Environment EC.* Bristol: Eunomia research and consulting.

EEA - European Environment Agency (2005). *Effectiveness of urban wastewater treatment policies in selected countries: an EEA pilot study.* European Environment Agency Report No 2/2005.

Eurostat (2020). The official web page of the European Commission Eurostat statistics, `https://ec.europa.eu/eurostat/home`, accessed on April 15th, 2020.

FAO (2018). *The State of Mediterranean and Black Sea Fisheries.* General Fisheries Commission for the Mediterranean, Italy: Rome.

Golam Zakaria, N.M, Rashid, K. and Khaled, I. (2017). *Environmental Pollution in Bangladesh by Inland Tanker Operation.* Procedia Engineering, 194, pp. 330–336.

Komadina, P., Brčić, D. and Frančić, V. (2013). *VTMIS služba u funkciji unaprjeđenja sigurnosti pomorskog prometa i zaštite okoliša na Jadranu.* Pomorski zbornik, 47–48, pp.27–40.

Lušić, Z. and Kos, S. (2006). *Glavni plovidbeni putovi na Jadranu.* Naše more, 53, 5-6/2006, pp.198–205.

Lušić, Z. Pušić, D. and Medić, D. (2017). *Analysis of the maritime traffic in the central part of the Adriatic.* In *Transport Infrastructure and Systems*, Dell'Acqua, G. and Wegman, F. (eds), Rome: CRC Press/Balkerma, 2017, pp.1013–1020.

Morović, M., Ivanov, A. and Oluić, M. (2016). *Mapping Oil Slicks in the Adriatic Sea: Croatia Case Study.* In *Oil Pollution in the Mediterranean Sea: Part II - National Case Studies*, Carpenter, A. and Kostianoy, A.G. (eds), Springer International Publishing, pp. 159 –178, doi:10.1007/698_2016_38.

Transport and Environment (2019). *One Corporation to Pollute Them All: Luxury cruise air emissions in Europe.* European Federation for Transport and Environment, Belgium:Brussels, doi: 10.1057/palgrave.mel.9100127.

UNEP/MAP-Plan Bleu (2009). *State of the Environment and Development in the Mediterranean.* UNEP/MAP-Plan Bleu, Athens.