# O.3.3 ANALYSIS TO ASSESS THE CARBON FOOTPRINT OF THE PASSENGERS' CHOICES

# Document Control Sheet

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# 1. Introduction

The aim and scope of the MIMOSA project is to create the knowledge and factual preconditions for more sustainable transport which nowadays need to be more environmentally friendly. Furthermore, this analysis draws on the knowledge to assess the carbon footprint of the passengers' choices. Also, this deliverable is grown from the O.3.5 Cross-border Transport Sustainability Action Plan and will be connected to the future deliverables of WP4 aiming at the definition of a Cross-border Transport Planning model (O.4.3) and of a position paper about low-carbon technological solutions (O.4.4). The following diagram frames this document in the strict context of its direct interlinkages with other MIMOSA outputs and deliverables.

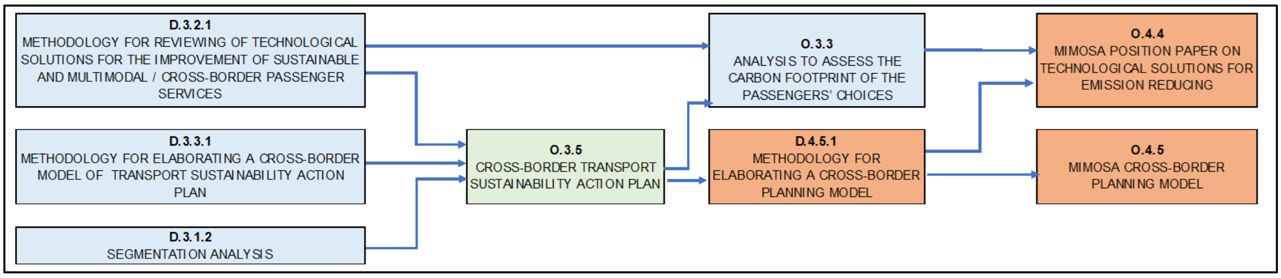



Figure 1. Interlinkages between this document, its direct premises and further steps

The Carbon footprint of the passengers' choices analysis is rooted in the fact that it is the predecessor to the future output documents. Furthermore, the information contained in the depicted deliverable and output documentation is of significant cross – border dimension because it will provide crucial decision-making guidelines for addressing and achieving the environmental sustainability of Italy – Croatia cross – border transport practices in terms of greenhouse gas (GHG) emissions reduction. The particular case of the Italy – Croatia cross – border area indicates trends of unimodal transport mode selection practices in terms of excessive utilization of private vehicles (cars). This creates further road transport networks overcapacity, bottlenecks, and GHG emissions, while negatively reflecting on the inclusion and implementation of environmentally friendlier transport modes such as trains, busses, and ships. Such practices will be mitigated within the stated deliverable and documentation by following the clear path set for achieving transport systems efficiency by reducing excessive car utilization, and by promoting sustainability benefits of public transport options within the maritime and hinterland domains.

Furthermore, the Analysis to assess the Carbon footprint of the passengers' choices is organized as follows. Chapter 2 presents the characteristics and significant emissions generated by different passengers' transport mode choices. Also, Carbon Footprint in

Transport Sector together with Reduction Initiatives is pointed. Chapter 3 presents the methodological framework for Carbon Footprint calculation with respect to different passengers' transport mode choices. The established methodology relies on the different technical characteristics and modes of operation for each transport mode entity, different industry regulations and models for calculating and reporting emissions, and data availability. Chapter 4 presents the Calculation of Carbon Footprint of Passengers' Transport Mode Choices – Italy-Croatia Case. Due to the research, passenger transportation mode choice in the specific region is based on Maritime, Road and Railway transportation mode. For this analysis, the current state of Italy – Croatia passenger transportation network is analyzed according to the several main regions identified in the Adriatic Sea area that connects Italy – Croatia national borders. After analyzing the importance of the specific origin and destination travel pairs defined in the Adriatic Sea area, the considered area is divided into three main regions: North Adriatic, Middle Adriatic, and South Adriatic. Based on the factors affecting the route selection in the defined Adriatic regions, the following routes were selected and divided accordingly into five case studies:

1. Case study 1: Venice – Pula – Poreč – Venice
2. Case study 2: Zadar – Ancona
3. Case study 3: Bari – Dubrovnik
4. Case study 4: Pesaro – Novalja – Mali Lošinj – Pesaro
5. Case study 5: Lignano – Grado – Trieste – Mali Lošinj

Chapter 5 is based on Case studies results with evaluation and comparative analysis from the established methodology considering the carbon footprint in kgCO2/trip-passenger according to the occupancy rates for each transportation mode choice. Furthermore, optimal transportation mode choice with respect to the different relative occupancy rates together with the total carbon footprint for each transportation mode based on the reference capacity is elaborated in this deliverable. Chapter 6 is based on flight emissions from travel between main Italy-Croatia programme area airports. The results of air travel emissions for four different aircrafts have been compared with other transportation nodes.

## 2. Characteristics and Significant Emissions Generated by Different Passengers' Transport Mode Choices

The European Union (EU) strongly promotes sustainable transitions within its economic, social, and environmental domains by constantly adopting new and revised strategic approaches, initiatives, and legislative acts with the aim of transforming the EU into a modern, resource efficient, and competitive geopolitical entity. This creates emphasis towards the EU member states' engagement in cooperative endeavours and activities that strive on improving their social and economic possibilities for creating a just, sustainable, and inclusive transformation of the European society and economy on a national territorial geospatial level and international cross – border geospatial level. It is important to state that unhindered socio – economic cooperation and progress is not possible without sufficient and appropriate transport infrastructure. This leads to the conclusion that transport infrastructure is a critical constituent in the connections of cross – border regions because it strongly influences interregional, local, and urban development. Thus, both member states of Italy and Croatia must accept the fact that the transport sector is an indispensable element of the Italy – Croatia cross – border area by regarding it as a crucial common tool for collective development and cohesion building.

The contemporary paradigm of sustainability dictates that transport systems are deemed sustainable when they possess the capacity for supporting the mobility needs of a society by adhering towards the least socially and environmentally detrimental mobility options in terms of preserving and enhancing the mobility needs of subsequent generations. Numerous environmentally friendly socio – economic aspects serve as indispensable evaluation factors for assessing the efficiency of transport systems from a sustainability perspective. The economic aspect of transport sustainability requires adherence towards factors such as enabling financial affordability in each transportation mode for every subsequent generation, fostering design and operations most suitable towards maximizing economic efficiency and cost reduction, creating a strong, diverse, and healthy economy. The societal aspect of transport sustainability requires adherence towards factors such as promoting social inclusivity by providing equity of access for people of all ages and social groups in each transportation mode for every subsequent generation, enhancing human health by adequate safety and security measures, limiting noise levels that create long – term detrimental effects on the individual and the community as transport users. The ecological aspect of transport sustainability requires adherence towards factors such as recycling natural resources in vehicles and infrastructure when they become obsolete (plastics, steel, glass, etc.), implementation of renewable power sources in terms of alternative and inexhaustible energy solutions (solar power from PV modules, electricity power from batteries etc.), coupling transport modes with circular economies in terms of mitigating GHG emissions and waste disposal in the environment by recycling and sequestrating.

However, the ecological aspect in specific terms of transport GHG emissions varies significantly in each individual transport mode due to differences in socio – economic characteristics of which the most influential are identified as occupancy rate, distance length, frequency of utilization, and price. Such GHG emissions variations dependency on individual characteristics of transport modes is further exacerbated in spillovers on macro levels due to significant variance and differences in technical characteristics, operations practices, industry regulations and standards, and data availability. Structural approaches towards addressing the aforementioned micro and macro levels in terms of mitigation efforts of transportation mode GHG environmental externalities are thoroughly researched within the MIMOSA project.

Between 2013 and 2019, greenhouse gas emissions from the EU's transport sector increased steadily, representing a trend that differed significantly from other sectors in the same period. Due to the decreased activity during the global COVID-19 pandemic, the preliminary estimates for 2020 show a significant drop in the emissions generated by the transport sector. However, after 2020, it is expected that transport emissions will increase again. The domestic transport emissions will only drop below the 1990 levels in 2029, according to the national predictions compiled by the European Environment Agency (EEA), even taking into account the actions currently proposed in the Member States. Moreover, the emissions generated by international transport, including international aviation and international maritime transport, are expected to continue to rise. [15]

Figure 2 shows the trend in the greenhouse gas emissions in the transport sector since 1990, as well as projections for the EU-27 until 2040. The data in Figure 2 also includes the preliminary emission estimates for 2020 submitted by the Member States. All domestic transport emissions are included in the data shown in Figure 2. However, this data does not include the emissions generated by the international aviation and international maritime transport, as well as the emissions generated by the production of electrical power used for transportation purposes, i.e., for the electrical propulsion of vehicles, such as electric cars, trains, and tramways. The greenhouse gas emissions, whose values are shown in Figure 2, are measured in a million tons carbon dioxide equivalent (Mt $CO_2$e). The projections denoted in Figure 2 as projections '**W**ith **E**xisting **M**easures' (WEM) include the already existing policies and measures for emission reduction. In contrast, the projections '**w**ith **a**dditional **m**easures' (WAM) represent the projections taking into account the future policies and measures planned by the Member States. [15,17,14,16]

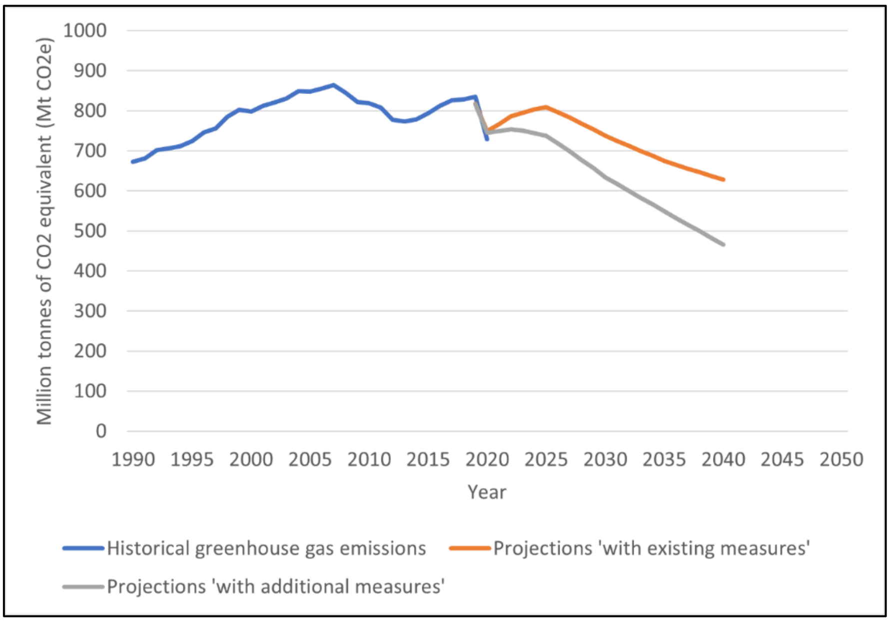



Figure 2. Greenhouse gas emissions from transport in Europe according to [15]

Between 2018 and 2019, the EU's domestic transport emissions saw an increase of 0.8%. As mentioned above, the global COVID-19 pandemic caused a dramatic decline in transportation activities, which resulted in the preliminary estimates for 2020 reporting the drop of 12.7% in the domestic transport emissions. This drop represents a substantial reduction, especially considering the comparison with the global economic crisis in 2008 that led to the decrease in the emissions in the following years, but only in the range of 1-3% per year. [15]

According to the national predictions done by the Member States, a significant rebound in transport emissions is expected beyond 2020. Without the proposal and proper implementation of the additional measures, an increase in the emission levels might be seen until 2025. The predicted reductions that would follow after would still leave transport emissions roughly 10% higher in 2030 than in 1990. However, if the additional measures and policies proposed to reduce transport emissions are adequately implemented by the Member States, the transport emissions would peak in 2022 and then decline. Emissions would thus be 6% lower in 2030 than they were in 1990. The majority of the planned and proposed policies and measures for reducing transport emissions promote electric cars and low-carbon fuels and promote the modal shift to public transport. [15]

Figure 3 shows the historical trend in the EU's greenhouse gas emissions generated by transport for the period between 1990 and the present, as well as the projections of the emission values up to 2040. The data in Figure 3 breaks down the total transport emissions into the individual subsectors, i.e., the different transport modes, including international aviation, international maritime transport, domestic aviation, road transport, domestic navigation, and railways. The data values shown for each transport mode represent the change in emission levels with respect to the level in 1990, denoted by the value of 100. Moreover, there are two types of emission value projections: WEM and WAM projections. [15,17,14,16]

As seen in Figure 3, the emissions generated by the domestic navigation and railways are the only ones whose values have decreased compared to the 1990 level. Moreover, only the emissions associated with road transport are expected to decrease until 2030. Besides the domestic transport categories, the international aviation and the international maritime transport modes are also considered to calculate the total greenhouse gas emission generated by the transport sector. The emissions from these two transport modes have increased since 1990. [15]

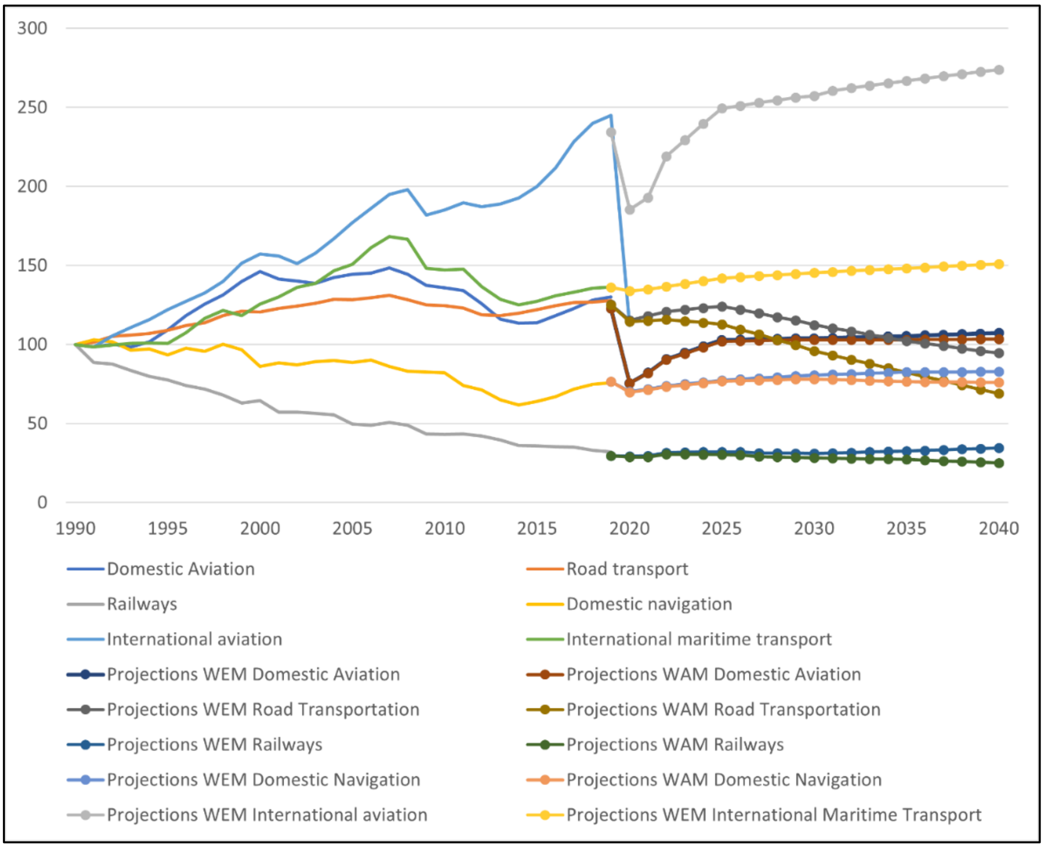



Figure 3. Greenhouse gas emissions from transport in the EU, including different transport modes and projection scenarios according to [15]

Figure 4 shows the share of the EU's transport greenhouse gas emissions by the individual transport modes in 2019. As seen in Figure 4, road transport generates 71.7% of all transport emissions, while

13.9% of the transport emissions are caused by aviation. The maritime transport emissions constitute 13.4% of the total transport emissions, 0.5% of the transport emissions are associated with the railways, and the rest (0.5%) are generated by the other transport modes. [18]

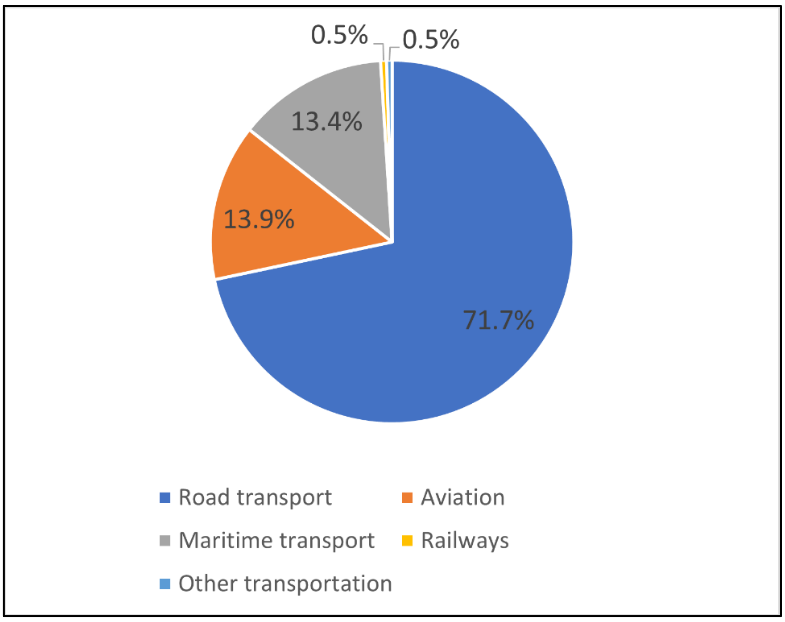



Figure 4. Share of the EU's transport greenhouse gas emissions by the individual transport modes in 2019

As seen in Figure 4, road transport represents the transport mode with the highest proportion of the total transport emissions, constituting 71.7% of all domestic and international transport greenhouse gas emissions in 2019. Therefore, most of the existing measures and the measures planned by the Member States are focused on emission reduction in the road transport sector. In addition, road transport decarbonizes faster than other transport modes, so its share in the total transport-generated emissions is expected to decrease. [15]

Figure 5 shows the proportions of the individual road transport modes in the total emissions generated by transport in 2019. As seen in Figure 5, the majority of the road transport emissions are produced by cars (44.3%). Moreover, heavy-duty trucks and buses generate 19.2%, while 8.7% of these emissions are generated by light-duty trucks. Motorcycles are responsible for 0.9% of the emissions, and the rest of the emissions are associated with other road transportation modes. [18]

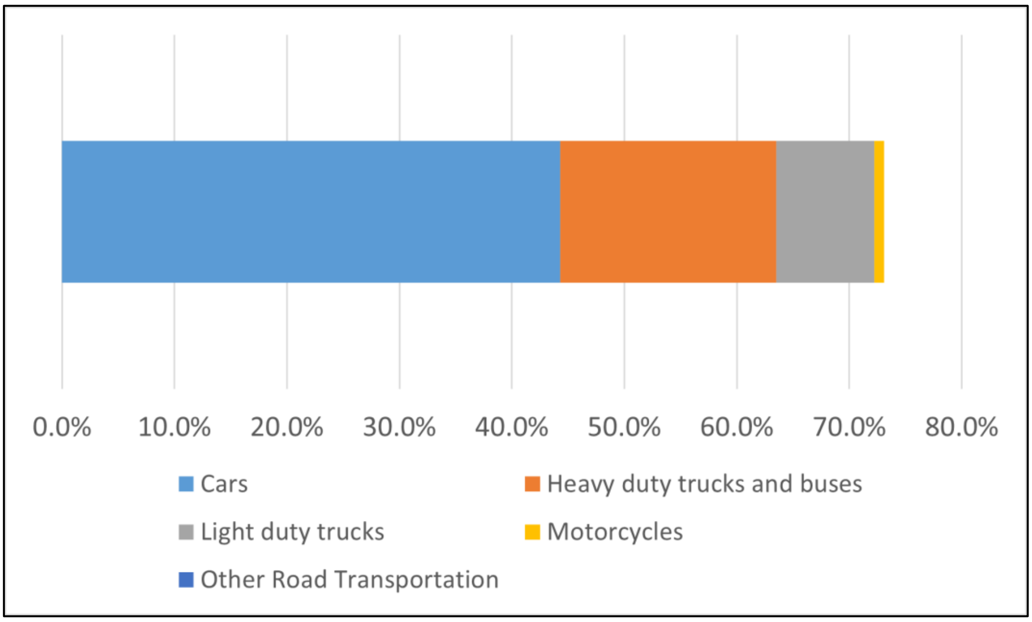



Figure 5. Share of the EU's transport greenhouse gas emissions generated by the road transport in 2019

The most significant increases in the emissions up to 2030 are expected in the aviation sector, followed by international maritime transport. Thus, these transport modes are expected to represent higher proportions of the total transport sector emissions in the future. The reason for the emission increase in these two subsectors lies in these subsectors not being prioritized in the national policies and emission reduction measures. [15]

Although the aviation sector was particularly affected by the COVID-19 pandemic in 2020, resulting in the emissions generated by international aviation being 54% lower in 2020 than in 2019, this reduction is expected to be temporary. Moreover, the flight numbers are expected to return to 2019 levels by 2024. [15,5]

## 2.1. Carbon Footprint – The Transport Sector

Many carbon footprint calculations have been conducted with a growing understanding of the importance of climate change and its representation in media and policies. These studies include various approaches: from the basic calculator tools available online to complex methods and life-cycle analyses. Carbon footprint represents the amount of gaseous emissions related to climate change and generated by human activities, including production and consumption. The methods to quantify carbon footprint include a broad spectrum of approaches, ranging from direct carbon dioxide ($CO_2$) emissions to full life-cycle greenhouse gas emissions expressed in $CO_2$ equivalents, which account for the climate effects of different gases, including methane, nitrous oxide, sulfur hexafluoride, etc. [36,32]

Carbon footprint analyses are also conducted for different sectors and subsectors of human activities, as well as for specific locations or regions. As elaborated above, the transport sector has a significant impact on total greenhouse gas emissions. Therefore, the calculation and analysis of the transport sector's carbon footprint, as well as the carbon footprint of the different transport modes comprised by it, are critical in planning and implementing initiatives and policies to reduce greenhouse gas emissions affecting climate change. Thus, many studies on the carbon footprint calculation in the transport sector can be found in the recent scientific literature. [27,31,28,25]

## 2.2 Carbon Footprint – Reduction Initiatives

The carbon-neutral EU requires the decarbonization of all sectors. This goal is aimed to be achieved by 2050, as defined by the European Green Deal (COM (2019) 640 final) [12]. The European Commission proposed to increase the intermediate target for the greenhouse gas emission reduction for 2030 to 55% in its proposal for the Climate Law (COM (2020) 80 final) [10]. The European Council accepted this proposal at the end of 2020. [15]

Furthermore, the European Commission published the 'Sustainable and Smart Mobility Strategy' (COM(2020) 789 final) [6] in December 2020. This document defined the plans for the green transformation of the EU transport sector. [15]

The transport sector causes above 30% of the EU's total greenhouse gas emissions. Moreover, when compared to other sectors, the transport sector has not experienced the same reductions in greenhouse gas emissions since 1990 due to the difficulties in its decarbonization. Therefore, the transport sector represents an important factor in the future reduction of greenhouse gas emissions and requires additional attention in implementing the already adopted policies and measures, as well as in defining the future measures by the EU Member States. [15]

The implementation of the 2030 Climate and Energy Framework [13] includes the commercial aviation sector being covered by the EU Emissions Trading Scheme [9,7,11]. Except for international shipping, all other transport modes are covered by the Effort Sharing Regulation [8]. [15]

# 3. Methodological Framework for Carbon Footprint Calculation With Respect to Different Passengers' Transport Mode Choices

The approach in the methodology to calculate the carbon footprint is different for each transport mode. The main reasons are:

- different technical characteristics and modes of operation for each transport mode entity,
- different industry regulations and models for calculating and reporting emissions,
- data availability.

The carbon footprint calculation for the maritime transport mode is based on the engine fuel consumption for the corresponding engine power on the particular route schedule. Route schedules are based on 2019 data, where the distribution of the ship operation is determined for each ship employed on a particular route. The ship operation distribution is based on the vessel speed calculation and the propulsion machinery load.

Table 1. Operation distribution of a single trip

| Ship operation (j) | Period ($t_i$) | Relative period (%) |
|---|---|---|
| Navigation (incl. man) ($j_1$) | $t_1$ | $t_1/S$ |
| Port stay origin ($j_2$) | $t_2$ | $t_2/S$ |
| Port stay destination ($j_3$) | $t_3$ | $t_3/S$ |
| | $S = \sum_{j1}^{j_3} t_j$ | $\sum_{n=1}^{3} t_n/S$ |

Vessel carbon footprint is calculated based on fuel consumed during particular trip and is calculated based on the IMO models presented in [23] and as mentioned in [35] and [34] with formulas:

$$\xi_{vCO2} = C_f \sum_{j=1}^{j=3} Fc_{t_j} \tag{1}$$

where fuel consumption is calculated:

$$Fc_{t_1} = \sum_{i=1}^{nME} P_{ME(i)}\, SFOC_{ME(i)} t_{(j1)} + P_{AE} SFOC_{AE} t_{(j1)} \tag{2}$$

and:

$$\sum_{j=2}^{j=3} Fc_{t_j} = \sum_{j=2}^{j=3} P_{AE} SFOC_{AE} t_{(j)} \tag{3}$$

The dependency of the propulsion engines load on the vessel speed is calculated with the Admiralty coefficient Ac, as described in [2]:

$$\sum_{i=1}^{nME} P_{ME(i)} = \frac{\sqrt[3]{D^2}}{A_c}\, {v_{eff}}^3 \tag{4}$$

The Admiralty coefficient Ac is calculated separately for each vessel based on the maximum service speed, main engines' maximum continuous rating (MCR) and vessel displacement. Afterwards, obtained coefficient is used to further calculate propulsion engine(s) power point based on actual vessel speed obtained from vessel schedule. Where auxiliary engines power data were not available, according to [24], the auxiliary engine's power is taken as:

- Auxiliary engine power for ferry vessels – 10% of main propulsion engine(s) power,
- Auxiliary engine power for high speed vessels – 5% of main propulsion engine(s) power.

Specific fuel oil consumption for diesel engines is taken as a function of the relative engine load, engine speed, and engine function:

$$SFOC\ = f\ (P_{REL}, RPM, ME/AE), \tag{5}$$

and is within the range of 180 - 340 g/kWh, as defined in [1].

The emission conversion factor $C_f$ is taken as 3.206 kg$CO_2$/kg fuel as defined by International Maritime Organization (IMO) [23]. This corresponds to the fuel grade marked as DMA in ISO 8217, which is taken as a base fuel for use onboard vessels during this research.

In the above-defined carbon footprint calculation procedure, the following variables are used:
$F_c$ – Fuel consumption (kg),
$P_{ME}$ – Propulsion engine power (kW),
$P_{AE}$ – Auxiliary engine power (kW),
*nME* – Number of main engines (total propulsion power)

*SFOC* – Specific fuel oil consumption (kg/kWh),
*t* – Timeframe period of single operation mode (h),
$C_f$ – Fuel - $CO_2$ conversion factor ($kgCO_2$/kg Fuel),
*j* - Number of vessel operation mode,
*i* – Number of main propulsion diesel engines,
$\xi_{vCO2}$ – Carbon footprint for a vessel ($kgCO_2$),
*D* – Vessel displacement (tons),
*Ac* – Admiralty coefficient,
$v_{eff}$ – Vessel speed (kn).

The carbon footprint calculation of the road transport mode is based on publicly available emission factors for average personal car and public buses. The average personal car is taken as a 5-seat car with an internal combustion engine. The usage of electric and hybrid cars in this study is not considered.

The average car age in the EU is taken as 10.7 years as per the Automotive Information center [21]. Accordingly, the average emission for newly registered cars in 2011 was 135.7 $gCO_2$/vehicle-km, and this was taken as an average for this research [19]. The obtained value is based on the New European Driving Cycle (NEDC) test methodology for new cars.

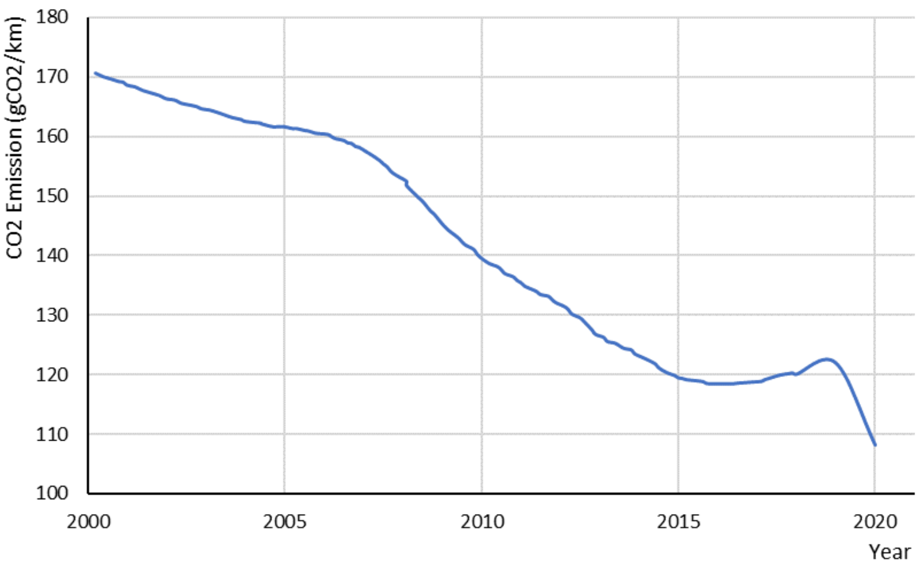



Figure 6. The average carbon footprint of a newly registered car in the EU, according to [19]

The carbon footprint for personal cars on a specific route is then calculated as:

$$\xi_{cCO_2} = \frac{E_{fc}}{1000}\, l_r, \tag{6}$$

where:
$\xi_{cCO2}$ – Carbon footprint for a personal car (kg$CO_2$),
$E_{fc}$ – Average car emission factor (g$CO_2$/km),
$l_r$ – Traveled distance (km).

The average bus size is based on a standard 49 seat bus with a diesel engine. Emission factors in g$CO_2$/km for buses are different based on the legislation for each EURO class and the different road types. The factors presented in Table 2 are based on emission tests on a limited sample of buses over different drive cycles carried out at different research facilities in Europe [4] and [38].

Table 2. $CO_2$ emissions from different bus emission classes from the UK GHG Inventory

| EURO Class | Emission based on road type (g$CO_2$/km) | | | |
|---|---|---|---|---|
| | Urban | Highway – Single Lane | Highway – Multi Lane | Motorway |
| **EURO I** | 1003 | 613 | 656 | 669 |
| **EURO II** | 905 | 600 | 640 | 654 |
| **EURO III** | 905 | 600 | 640 | 654 |
| **EURO IV** | 878 | 582 | 620 | 635 |
| **EURO V** | 851 | 564 | 601 | 615 |
| **EURO VI** | 787 | 521 | 556 | 568 |

An average of 601 gCO2/km is taken in this research. In that case, the average emission factor is taken for Highway – Multi Lane. The gradation emission factor for each road type on a particular route was not considered. The carbon footprint for a public bus is calculated with the same model as a personal car, except different emission factor is used:

$$\xi_{bCO_2} = \frac{E_{fb}}{1000}\, l_r, \tag{7}$$

where:
$\xi_{bCO2}$ – Carbon footprint for a public bus (kg$CO_2$),
$E_{fb}$ – Average bus emission factor (g$CO_2$/km),
$l_r$ – Traveled distance (km).

Road distances for personal cars are estimated to be the same, i.e.; it was not considered that public buses on the observed routes might have additional waypoints (public bus stations).

Railway carbon footprint is calculated based on the fixed emission factors available for electric trains, while for diesel railway segments is calculated as per fuel consumption and average speed on non-electrified railway sections. Average emission factor for electric train is taken as 6 g CO2e per passenger-km as emission presented by Eurostar and DEFRA [40]. Average carbon footprint for non-electrified railway sections is calculated based on average fuel consumption which taken as 60 lit/h [30] and average train speed in Croatia (non-electrified railroad sections are located only in Croatia). Average speed is taken as 45,93 km/h [42]. Train capacity is based on 209 seat capacity for Gredelj Low Floor Diesel Multiple Unit [39] and employed within Croatian passengers' railways as conventional train model. Fuel used in trains is based on diesel fuel with specific gravity of 0,890 kg/ltr as per ISO 8217. Conversion factor for fuel to $CO_2$ in this case is taken as 3,140 $kgCO_2$/kg fuel as defined by EEA [30].

Considering that the railway cannot reach some destinations due to the infrastructure being nonexistent, the carbon footprint is then calculated based on the railway transportation to the closest public railway station. In this case, the carbon footprint calculation for the remaining distance considers the bus transportation mode by considering the average number of buses required to reach train capacity. Therefore, depending on the railway infrastructure destinations availability, a totality of four different railway carbon footprint models are utilized as follows:

1. Carbon footprint calculation model for using electrified railways on a route:
$$\xi_{teCO2} = C_s \, \frac{E_{ftpax}}{1000} \, l_{te} \tag{8}$$
2. Carbon footprint calculation model for using non-electrified railways on a route:
$$\xi_{tneCO2} = 2{,}7946 \, \frac{Fc_{travg}}{v_{traavg}} \, l_{tne} \tag{9}$$
3. Carbon footprint calculation model for using a combination of electrified railway section, non-electrified railway section and public bus on a railway route:
$$\xi_{tcCO2} = \xi_{teCO2} + \xi_{tneCO2} + 0{,}004 \; E_{fb} \, l_r \tag{10}$$
4. Carbon footprint calculation model for using a combination of electrified railway section and public bus on a railway route:
$$\xi_{tcCO2} = \xi_{teCO2} + 0{,}004 \; E_{fb} \, l_r \tag{11}$$

in where:
$\xi_{teCO2}$ – Carbon footprint for electrified railway route ($kgCO_2$),
$\xi_{tneCO2}$ – Carbon footprint for non-electrified railway route ($kgCO_2$),
$\xi_{tcCO2}$ – Carbon footprint for railways (electric and non-electric) and public bus on combined railway route ($kgCO_2$),
$E_{ftpax}$ – Average railway emission factor for electric trains ($gCO_2$/passenger-kilometer),

$E_{fb}$ – Average bus emission factor ($gCO_2$/km),
$l_r$ – Traveled distance by public bus (km),
$l_{te}$ – Distance of electrified railway section (km),
$l_{tne}$ – Distance of non-electrified railway section (km),
$Fc_{travg}$ – Average diesel train fuel consumption per hr (ltr/hr),
$v_{travg}$ – Average diesel train speed (km/h),
$C_s$ – Average train capacity (taken as 209 for model train assumption).

# 4. Calculation of Carbon Footprint of Passengers' Transport Mode Choices – Italy-Croatia Case Studies

## 4.1. Current state of Italy-Croatia interconnection network

For this research, the current state of Italy – Croatia passenger transportation network is analyzed according to the several main regions identified in the Adriatic Sea area that connects Italy – Croatia national borders. Moreover, the analysis takes into account the different transportation mode choices available for travel realization.

After analyzing the importance of the specific origin and destination travel pairs defined in the Adriatic Sea area, the considered area is divided into three main regions: North Adriatic, Middle Adriatic, and South Adriatic. The defined regions are depicted in Figure 7.

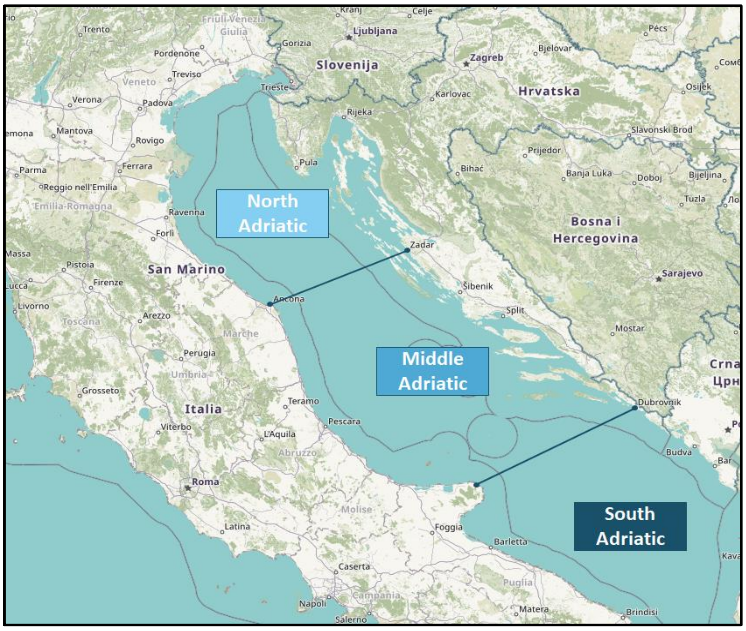



Figure 7. Main Adriatic regions

Furthermore, the current state (based on 2019 data, prior COVID-19 period) of the Italy – Croatia traveling network is analyzed, considering the importance of the specific origin and destination pairs and their location in the defined regions. Available passenger transportation mode choices in the defined regions include:

- Maritime transportation mode choice,
- Road transportation mode choice,
- Railway transportation mode choice.

The airway transportation mode choice has not been taken into account for the analysis and it will not be mentioned and developed any further. That decision is primarily due to the service inconsistency and significant effects in the decreasing demand for that transportation mode choice due to the recent COVID-19 pandemic. Every defined region is specific regarding the availability of mentioned transportation mode choices. Those specifics are based on the acceptable time-distance proportion where not every transportation mode is preferable for overcoming the particular distances. Also, it is essential to specify that not all transportation modes are available in each of the defined regions.

Furthermore, the maritime transportation mode choice represents a reference for selecting origin-destination. Regarding the mentioned approach, the identified routes have been distributed within the predefined Adriatic regions as shown in Table 3 and Figure 8.

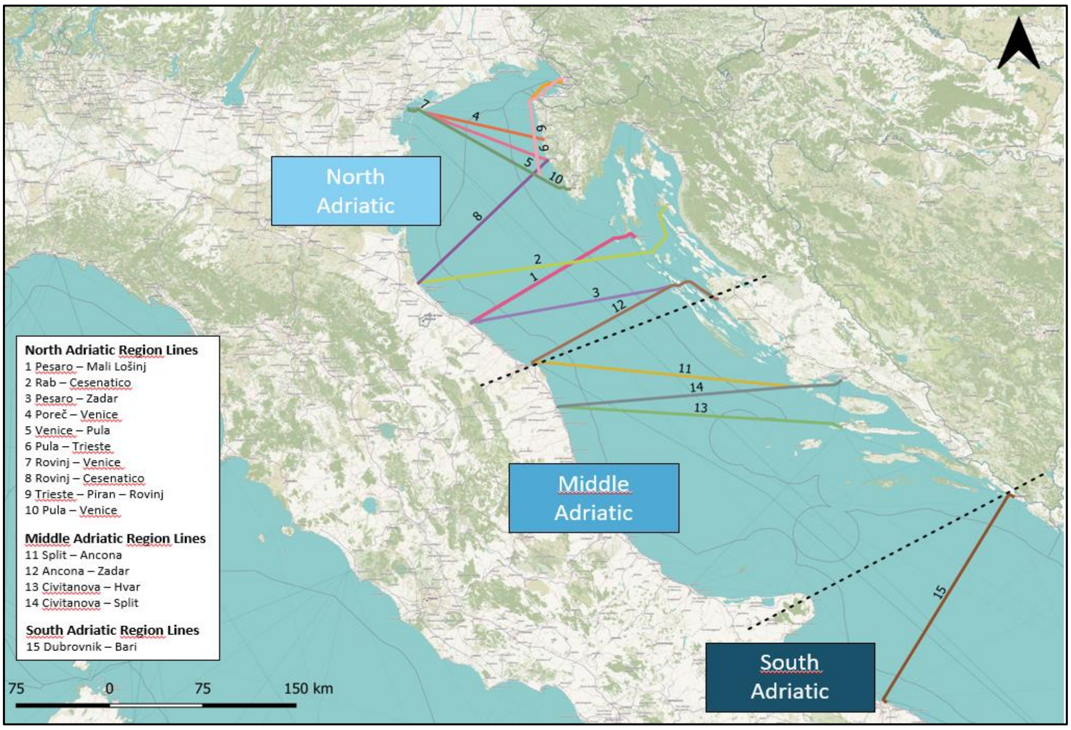



Figure 8. Distribution of maritime transportation lines in the defined Adriatic regions

Table 3. Distribution of maritime transportation lines in the defined Adriatic regions

| North Adriatic region | Middle Adriatic region | South Adriatic region |
|---|---|---|
| Pesaro - Mali Lošinj | Split - Ancona | Dubrovnik - Bari |
| Lignano – Grado – Trieste – Mali Lošinj | Ancona - Zadar | |
| Rab - Cesenatico | Civitanova - Hvar | |
| Pesaro - Zadar | Civitanova - Split | |
| Poreč - Venice | | |
| Venice - Pula | | |
| Pula - Trieste | | |
| Rovinj - Venice | | |
| Rovinj - Cesenatico | | |
| Trieste - Piran - Rovinj | | |
| Pula - Venice | | |

For the carbon footprint calculation and further comparison, several routes from Table 3 have been selected depending on the different combinations of the transportation mode choices available for their realization.

Furthermore, the travel distance is also identified as a significant factor in the route selection as it is closely related to calculating the carbon footprint. Among various midpoint combinations for achieving specific destination points on routes (especially when road or railway transportation mode choice is taken into account), finding the shortest path also represents a significant selection factor.

The additional selection factors were also considered in this study. These factors include transportation entity type (e.g., not all destinations can be reached by the same vessel type), trips/voyages frequency in the considered time period, passenger flow intensity in the considered time period, and average passenger occupancy.

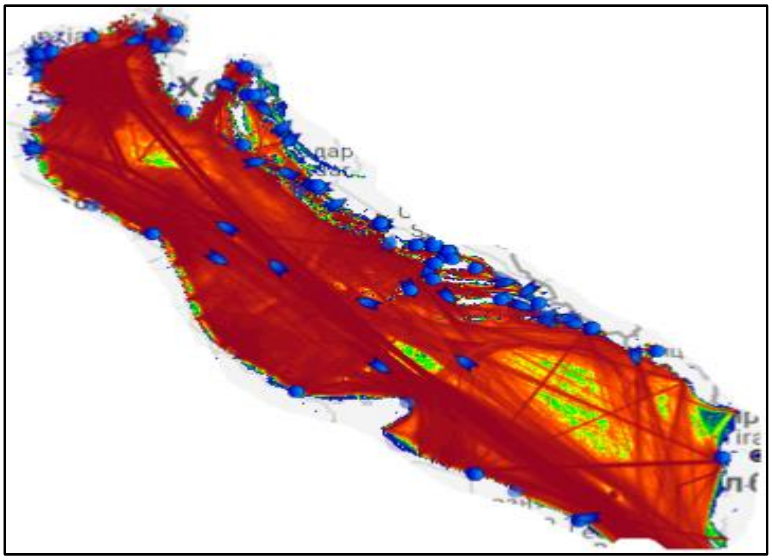


Figure 9. The intensity of ferry routes in the Adriatic Sea (Summer period, 2019), according to [26]

Based on the mentioned factors affecting the route selection in the defined Adriatic regions, the following routes were selected and divided accordingly into five case studies:

1. Case study 1: Venice – Pula – Poreč – Venice
2. Case study 2: Zadar – Ancona
3. Case study 3: Bari – Dubrovnik
4. Case study 4: Pesaro – Novalja – Mali Lošinj – Pesaro
5. Case study 5: Lignano – Grado – Trieste – Mali Lošinj

**Venice – Pula – Poreč – Venice** route is chosen primarily for its significance for the North Adriatic region. Its significance is indicated by the 16,272 passenger flows intensity (in 2019) achieved by 44 voyages, resulting in the average vessel occupancy per trip of 56%.
The chosen route can be accomplished by various transportation mode choices, indicating a multimodal destination reach.

**Zadar – Ancona** route is significant for the Middle Adriatic Region due to the 36,333 passenger flows intensity in 2019 achieved by 96 voyages. The presented data indicates average vessel occupancy per trip of 28.5%. The route is also chosen because it can be accomplished by all defined passenger transportation mode choices.

**Bari – Dubrovnik** route is the main route in the South Adriatic Region. In that case, 87 voyages were performed in 2019, where 69,049 passengers were transported. That indicates average vessel occupancy per trip of 30.5%.

On the next route, **Pesaro – Novalja – Mali Lošinj** – **Pesaro**, the total passenger flow intensity of 11,660 passengers was achieved by 60 voyages. Those data indicate average vessel occupancy per trip of 24.9%.

The last selected route, **Lignano – Grado – Trieste – Mali Lošinj**, is chosen as it connects four important passenger transport origins and destinations in Northern Adriatic. On route segment Trieste – Mali Lošinj, in 2019, a total of 81 voyages was performed, with a total number of passengers transported of 3.805, with an indicate average vessel occupancy per trip of 46,9%.

Furthermore, for the selected routes, the availability of particular passenger transportation mode choices and the corresponding distances are determined by Open CPN 5.0.0 + 9065270 following all navigational rules and good seamanship practice (maritime transportation mode choice) and QGIS software extension for OpenStreetMap query requests (road and railway transportation mode choices).

## 4.2. Case Study 1: Carbon footprint calculation for Venice – Pula – Poreč route

Venice – Pula – Poreč – Venice route consists of several destinations as waypoints. The route is defined as a closed circled route located in the North Adriatic region. Therefore, the route is segmented into three major segments: Venice – Pula, Pula – Poreč, and Poreč – Venice. The distances between the destinations are, in this case, shorter than the ones on other selected routes.

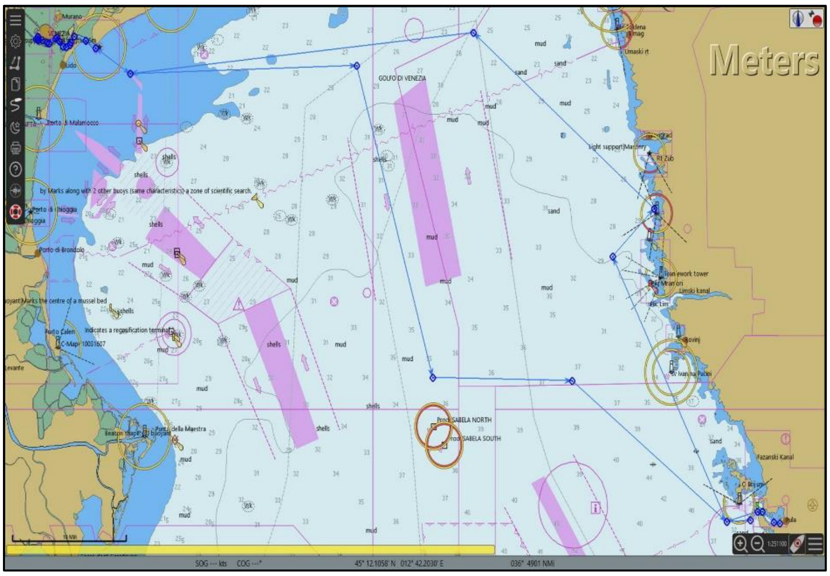



Figure 10. Route Venice – Pula - Poreč (Maritime transportation mode)

As the origin/destination point of the selected route, the port of Venice is one of the major Italian passenger ports in the North Adriatic. It is located on the northeastern part of the Italian mainland and serves as a base on the existing passenger lines to/from Croatia chosen for this research. The port of Pula is located on the northwestern part of the Croatian mainland, in the south of the Istrian peninsula. The port serves as the actual origin/destination point of the chosen passenger line. The port of Poreč is located on the northwestern part of the Croatian mainland in the Istrian peninsula. The port serves as the virtual origin/destination point on the considered passenger line. The passenger lines for which the ports mentioned above present origins or destinations are listed in Table 4.

Table 4. Passenger lines serviced in 2019 for the existing Pula – Venice route

| **Existing passenger lines (Line operator)** | **Vessel name** | **Average passenger occupancy per trip in 2019** | **Number of vessel voyages in 2019** |
|---|---|---|---|
| Pula – Venice (Venezia Lines LTD) | San Pawl | 56% | 44 voyages |
| Poreč – Venice (Venezia Lines LTD) | San Pawl | 30.6% | 88 voyages |

For the maritime transportation mode choice, the vessel “San Pawl” (IMO Number: 8815932) with 389 GT and passenger capacity of 330 is used as a reference vessel based on which carbon footprint calculation is conducted. The technical characteristics of the reference vessel are shown in Table 5.

Table 5. Technical characteristics of the reference vessel “San Pawl”

| **Technical characteristics: Vessel “San Pawl”** | |
|---|---|
| Vessel type | HSC air cushion |
| Summer DWT | 50 t |
| LOA (Length over all) | 35.3 m |
| Breadth | 11.5 m |
| Draught | 2.05 m |
| Propulsion type | 2x fixed pitch propellers |
| Propulsion power | 3,358 kW |

The carbon footprint calculation for the road transportation mode choice is conducted on either personal car or public bus entities. Traveling by road transportation mode choices consists of traveling on motorways, highways, and local roads. The direct railway connection exists between Venice and Pula, where the Italy and Slovenia section is covered by electrified railway route while railway section in Istria is covered by non-electrified railway route. In this particular case, Poreč can be reached only through a rail junction in Pazin with the assumption of taking a public bus to and from Poreč. Therefore, for carbon footprint calculation assumption was made to take public bus from the nearest railway station to and from Poreč. Bus capacity is adjusted and assumed to be the same as train capacity (209 pax ⇒ approx. 4 buses). In this case, railway transportation mode choice could be chosen only as a part of an intermodal trip.

The total distance determined for Venice – Pula – Poreč – Venice route, i.e., its segments, is shown in Table 6.

Table 6. Determined distances on the selected Venice – Pula – Poreč – Venice route

| Route Segment | Maritime transportation mode choice (Nm) | | | Road transportation mode choice (km) | | | Railway-Road transportation mode choice (km) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maneuvre | Sea passage | Total | Road | Maritime | Total | Railway (nonel./el) | Road | Total |
| Venice – Pula | 12.7 | 63.5 | 76.2 | 283 | 0 | 283 | 106.4/186.9 | 0 | 293.3 |
| Pula – Poreč | 3.8 | 26.6 | 30.4 | 56 | 0 | 56 | 49.1/0 | 32.7 | 81.8 |
| Poreč – Venice | 10.7 | 50 | 60.7 | 250 | 0 | 250 | 57.3/186.9 | 32.7 | 276.9 |

The maritime transportation distances on the route segment Venice – Pula (Figure 11), provided in Table 7, are calculated based on the specific navigation modes considering the port features. The defined navigation modes include manoeuvring on departure, sea passage, and manoeuvring on arrival.

Table 7. Distances in the specific navigation modes on the route segment Venice – Pula

| | | |
|---|---|---|
| Route segment: Venice – Pula | Maneuvring on departure | 9.8 Nm |
| | Sea passage | 63.5 Nm |
| | Maneuvring on arrival | 2.9 Nm |

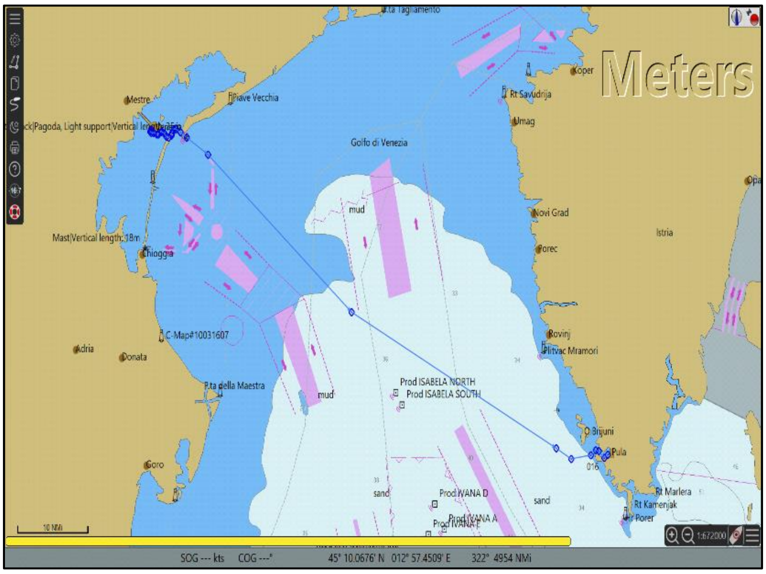



Figure 11. Route segment Venice – Pula (Maritime transportation mode)

The road transportation mode on the Venice – Pula route segment (Figure 12) is realized by personal car or public bus on the following road segments:

- Italy: highway SR11 and motorway A4 (part of European route E70) – from Venice to Trieste,
- Slovenia: highway H5 and H6 (part of European route E751) – from border crossing Škofija to border crossing Dragonja, and
- Croatia: motorway A9 (part of European route E751) – from Dragonja to Pula.

The total calculated road distance for the mentioned route segment is 283 km.

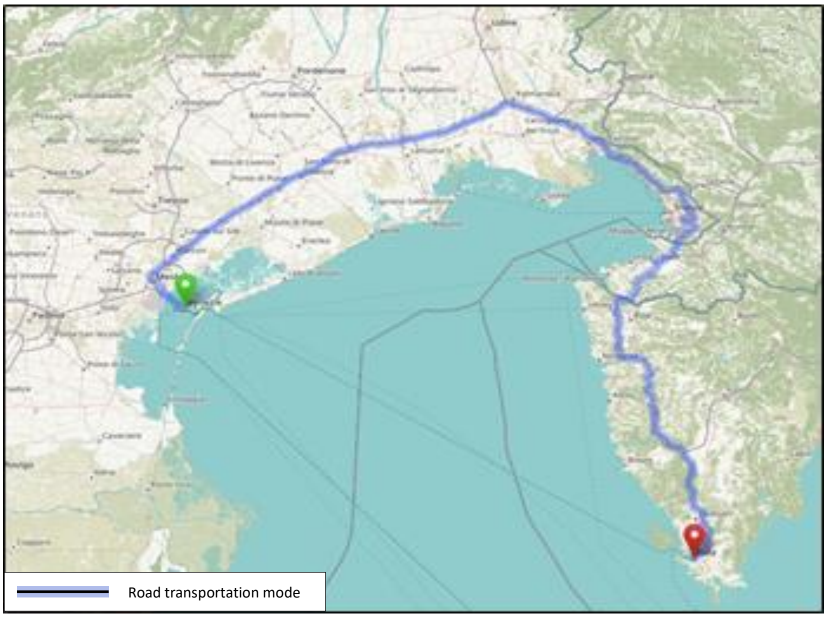



Figure 12. Route segment Venice – Pula (Road transportation mode)

The total traveling distance covered by the railway transportation mode on the route segment Venice – Pula consists of several sections (Figure 13). The first section is located in Italy (Venice – Trieste – Villa Opičina), with a total distance of 153.8 km. The next two sections are located in Slovenia (Villa Opičina – Divača – Prešnica and Prešnica – Rakitovec), with a total distance of 46.9 km. The last section is located in Croatia (Rakitovec – Pazin – Pula), with a total distance of 92.4 km. The complete distance considered in the calculation of the carbon footprint for this segment is 293.3 km. The railway section between Prešnica and Pula is not electrified and has to be covered by diesel train at a distance of 106.5 km.


Figure 13. Route segment Venice – Pula (Railway transportation mode)

The next route segment, Pula-Poreč (Figure 14), is a virtual one chosen to compare the possibility of a circular route with short distances between two destinations, one of which cannot be reached by railway. Maritime distances for this segment regarding the applied navigation modes are shown in Table 8.

Table 8. Distances in the specific navigation modes on the route segment Pula – Poreč

| | | |
|---|---|---|
| Route segment: Pula – Poreč | Maneuvering on departure | 2.9 Nm |
| | Sea passage | 26.6 Nm |
| | Maneuvering on arrival | 0.9 Nm |

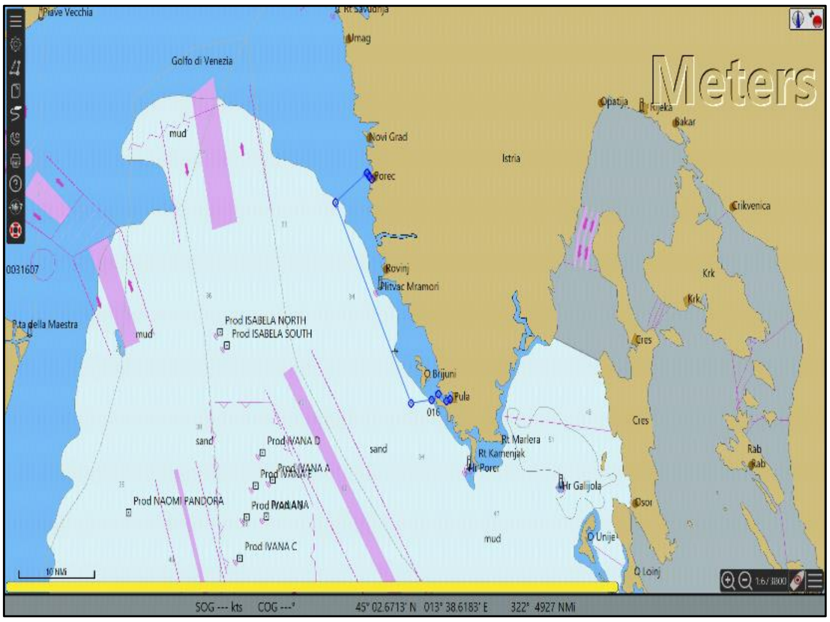



Figure 14. Route segment Pula – Poreč (Maritime Transportation mode)

The road transportation mode on the Pula – Poreč route segment (Figure 15) is realized by personal car or public bus on the following road segments: Croatia: motorway A9 (part of European route E751) and state road D302 – from Pula to Baderna and from Baderna to Poreč, respectively.
The total calculated road distance for the mentioned route segment is 56 km.

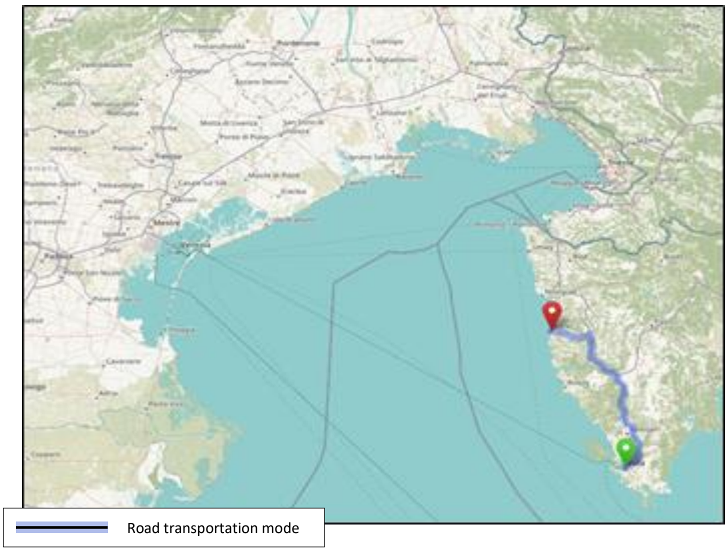



Figure 15. Route segment Pula – Poreč (Road transportation mode)

The total distance travelled by railway transportation mode on the Pula – Poreč route segment (Figure 16) consists of one section in Croatia (Pula – Pazin), with a total length of 49.1 km. The existing railway infrastructure can't provide direct travel but only throughout a rail junction in Pazin with the assumption of taking public bus to and from Poreč. This section of the railway is not electrified, and it needs to be covered by diesel train. The section between Pazin and Poreč is assumed that it is covered by the per public bus transportation mode to reach the final destination. The distance on the given section is 32.7 km and includes:

- Croatia: state road D48 and D302 – from Pazin to Baderna and from Baderna to Poreč, respectively.

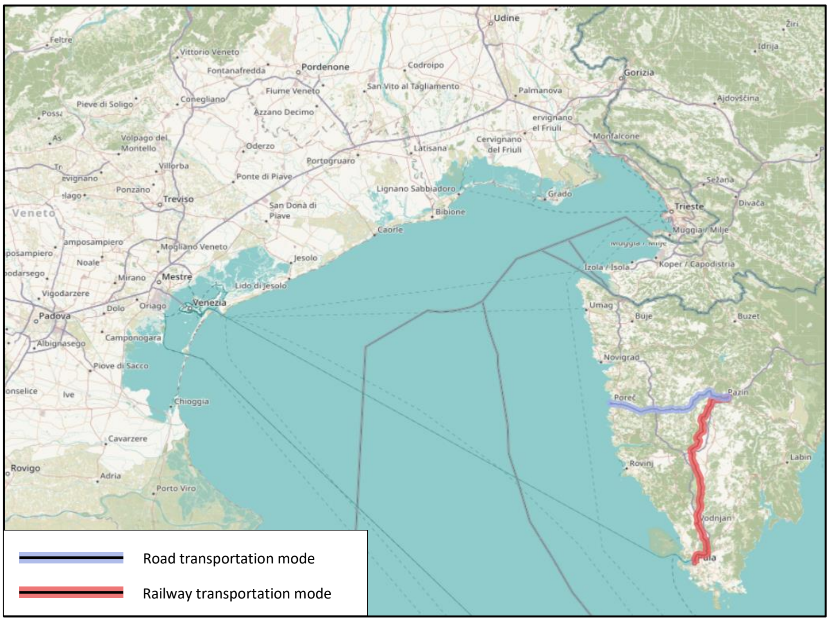



Figure 16. Route segment Pula – Poreč (Railway transportation mode)

The route segment, Poreč – Venice, presents the last segment of the presented circled route. Maritime distances for this segment (Figure 17) regarding the applied navigation modes are shown in Table 9.

Table 9. Distances in the specific navigation modes on the route segment Poreč – Venice

| | | |
|---|---|---|
| | Maneuvering on departure | 0.9 Nm |
| Route segment: Poreč – Venice | Sea passage | 50.0 Nm |
| | Maneuvering on arrival | 9.8 Nm |

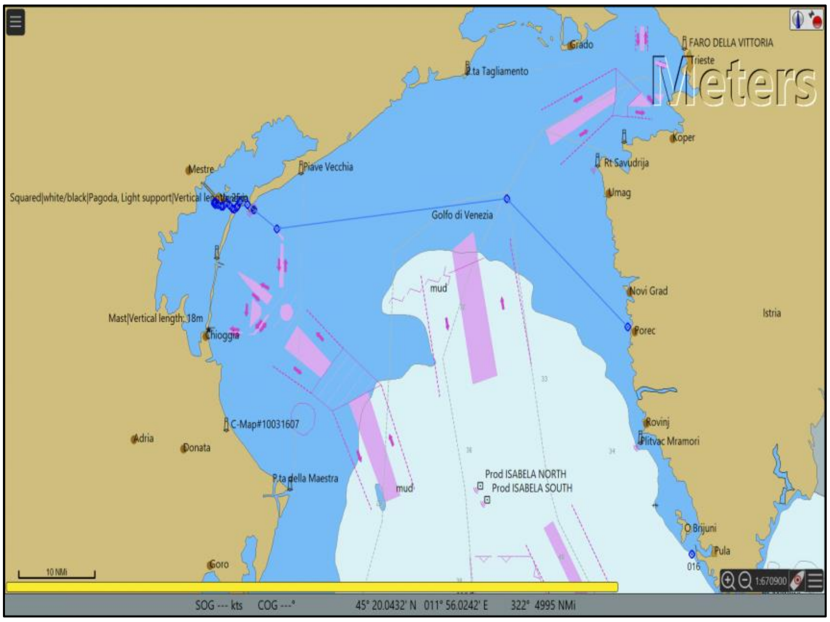



Figure 17. Route segment Poreč – Venice (Maritime transportation mode)

The road transportation mode on the route segment Poreč – Venice (Figure 18) is realized by personal car or public bus on the following road sections:

- Croatia: state road D302 and motorway A9 (part of European route E751) – from Poreč to Baderna and from Baderna to Dragonja, respectively,
- Slovenia: highway H5 and H6 (part of European route E751) from border crossing Dragonja to border crossing Škofija, and
- Italy: motorway A4 and highway SR11 (part of European route E70) – from Trieste to Venice.

The total calculated road distance for the mentioned route is 250 km.

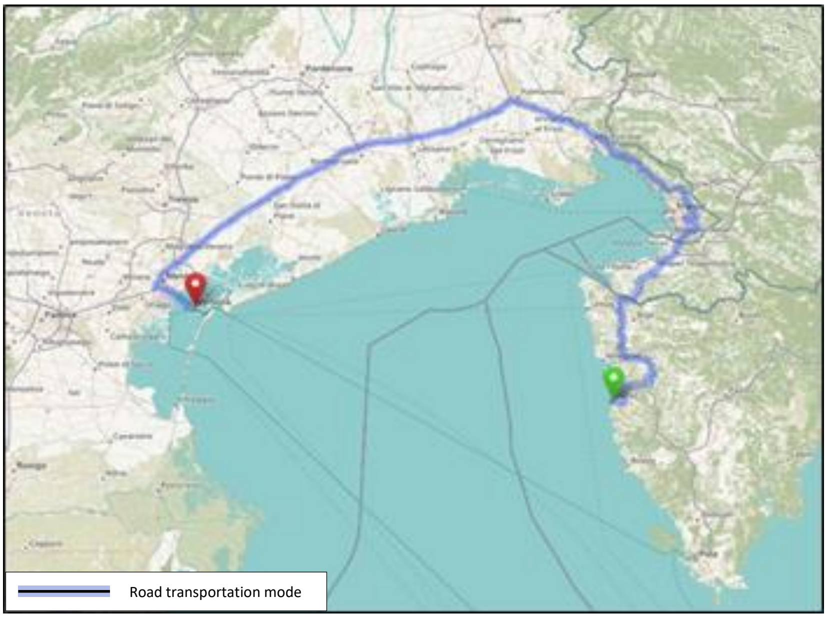



Figure 18. Route segment Poreč – Venice (Road transportation mode)

The distance travelled by railway transportation mode on the Poreč – Venice route segment (Figure 19) includes the section that has to be covered by personal car or public bus. This section, with a total distance of 32.7 km, includes traveling on the following:

- Croatia: state road D302 and D48 – from Poreč to Baderna and from Baderna to Pazin, respectively.

The rest of the segment (Pazin – Venice) can be accomplished by the railway transportation mode where section Pazin – Prešnica has to be covered by a non - electrified railway in a total distance of 57.3 km. The remaining section of the railway Prešnica – Divača – Villa Opičina – Trieste Airport – Venice is electrified through its entire length of 186.8. The total distance of the railway transportation mode is 244.1 km.


Figure 19. Route segment Poreč – Venice (Railway transportation mode)

## 4.3. Case Study 2: Carbon footprint calculation for Ancona – Zadar route

The selected route Zadar – Ancona is defined as a single route located in the Middle Adriatic region. Distances between destinations are larger than ones presented in the previous route.

The port of Zadar (Gaženica), as an actual origin/destination port, is a deepwater port and represents the most significant economic and business zone in Zadar County. It is also located at the border between the Northern Adriatic and Middle Adriatic regions.

As an actual origin/destination port, the port of Ancona is located in the middle of the Italian Adriatic coast, in the Gulf of Ancona, at the border between Northern Adriatic and Middle Adriatic regions. The port serves as a base for the existing passenger line to/from Croatia chosen in this research.

The passenger lines for which the ports mentioned above present origins or destinations are listed in Table 10.

Table 10. Passenger lines serviced in 2019 for the existing Ancona – Zadar route

| Passenger line (Line operator) | Vessel name | Average passenger occupancy per trip in 2019 | Number of vessel voyages in 2019 |
|---|---|---|---|
| Ancona – Zadar (Jadrolinija) | Zadar | 28.5% | 49 voyages |

For maritime transportation mode choice, the vessel "Zadar" (IMO Number: 9021485) with 9,487 GT, passenger capacity of 1,300, and vehicle capacity of 280 is used as a reference vessel based on which carbon footprint calculation is conducted. The technical characteristics of the reference vessel are shown in Table 11.

Table 11. Technical characteristics of the reference vessel "Zadar"

| Technical characteristics: Vessel "Zadar" | |
|---|---|
| Vessel type | Ro-PAX Ferry |
| Summer DWT | 2,152 t |
| LOA (Length over all) | 116 m |
| Breadth | 18.9 m |
| Draught | 5.15 m |
| Propulsion type | 2x CPP propellers |
| Propulsion power | 7,000 kW |

The carbon footprint calculation for the road transportation mode choice is conducted on either personal car or public bus entities. Traveling by road transportation mode choices consists of traveling on motorways, highways, and local roads through the fastest route through Rijeka (Bosiljevo junction). By railway transportation mode, the destination can be reached either by Ancona – Ljubljana – Zagreb – Zadar or Ancona – Rijeka – Zadar route. The second route is selected for further calculation based on the defined shortest path principle as it generates a more acceptable time-distance proportion and a more acceptable carbon footprint value. The total distance determined for Ancona – Zadar route, is shown in Table 12.

Table 12. Determined distances on the selected Ancona – Zadar route

| | Maritime transportation mode choice (Nm) | | | Road transportation mode choice (km) | | | Railway-Road transportation mode choice (km) | | |
|---|---|---|---|---|---|---|---|---|---|
| **Route** | **Maneuver** | **Sea passage** | **Total** | **Road** | **Maritime** | **Total** | **Railway (nonel./el)** | **Road** | **Total** |
| Ancona – Zadar | 6.7 | 84.7 | 91.4 | 864 | 0 | 864 | 733.4/318.3 | 0 | 1,051.7 |

The maritime transportation distances on the route Ancona – Zadar (Figure 20), provided in Table 13, are calculated based on the specific navigation modes taking into account the port features.

Table 13. Distances in the specific navigation modes on the route Ancona – Zadar

| | | |
|---|---|---|
| **Route: Ancona – Zadar** | Maneuvering on departure | 4.2 Nm |
| | Sea passage | 84.7 Nm |
| | Maneuvering on arrival | 2.5 Nm |

The average vessel speed on the route mentioned above is assumed to be 10.11 kn, based on 2019 operational timetables.

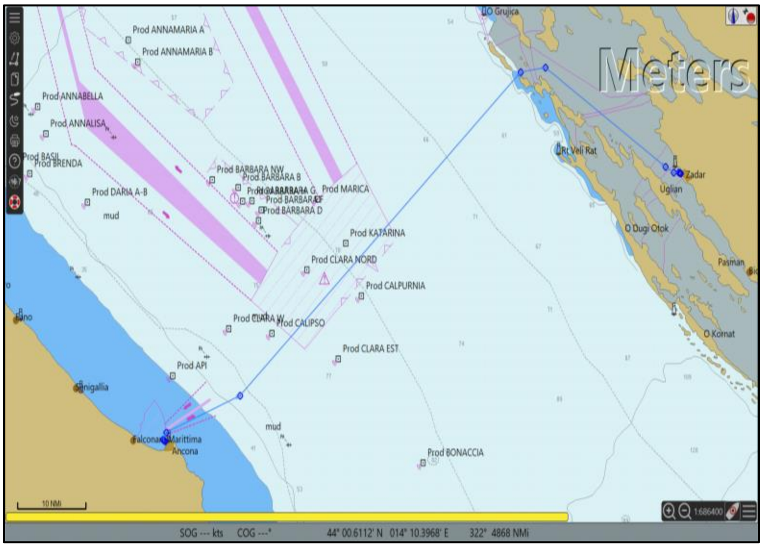



Figure 20. Route Ancona – Zadar (Maritime transportation mode)

The road transportation mode on the Ancona – Zadar route (Figure 21) is realized by personal car or public bus on the following road segments:

- Italy: motorway A14 (part of European route E55), A13, A4, and highway SS14 - from Ancona to Bologna, from Bologna to Padua, from Padua to Trieste, and from Trieste to border crossing Krvavi Potok, respectively,
- Slovenia: state road G7 – from border crossing Krvavi Potok to Starod,
- Croatia: highway D8, motorways A7, A6, A1, and state road D424 – from Pasjak to Rupa, from Rupa to Orehovica, from Orehovica to junction Bosiljevo, from junction Bosiljevo to Zadar I, from Zadar I to port of Zadar (Gaženica), respectively.

The total calculated road distance for the mentioned route is 864 km.

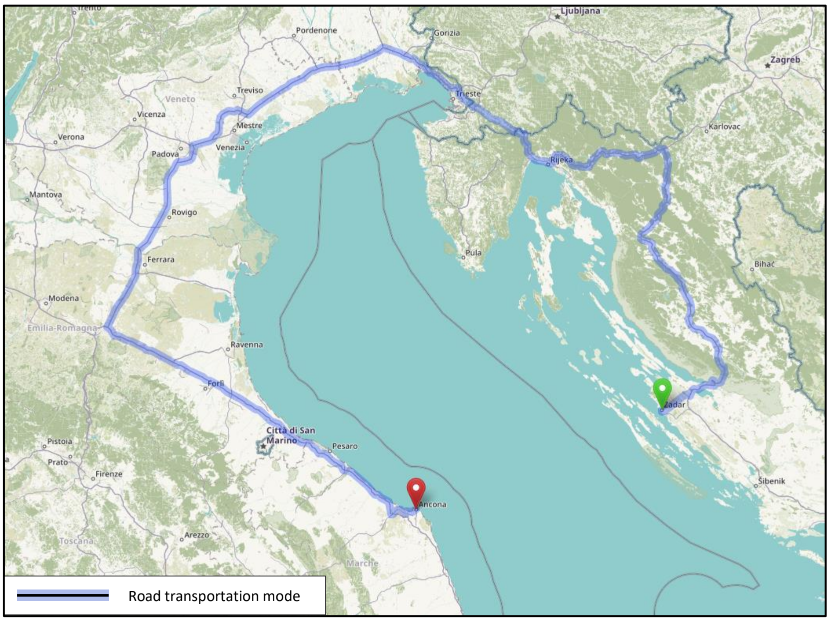



Figure 21. Route Ancona – Zadar (Road transportation mode)

The total traveling distance covered by the railway transportation mode on the route Ancona – Zadar consists of several sections (Figure 22). The first two route sections are located in Italy (Ancona – Bologna, and Bologna – Venice – Trieste – Villa Opičina), with a total distance of 517.3 km. The section located in Slovenia consists of traveling on relations Villa Opičina – Divača – Pivka, and Pivka-Šapjane, with a total distance of 68.6 km. The first section located in Croatia is an electrified one (Šapjane – Rijeka – Ogulin), with a total distance of 147.5 km, followed by the second non-electrified one (Ogulin – Knin – Zadar), with a total distance of 318.3 km. The complete distance considered in the calculation of the carbon footprint for this segment is 1,051.7 km.

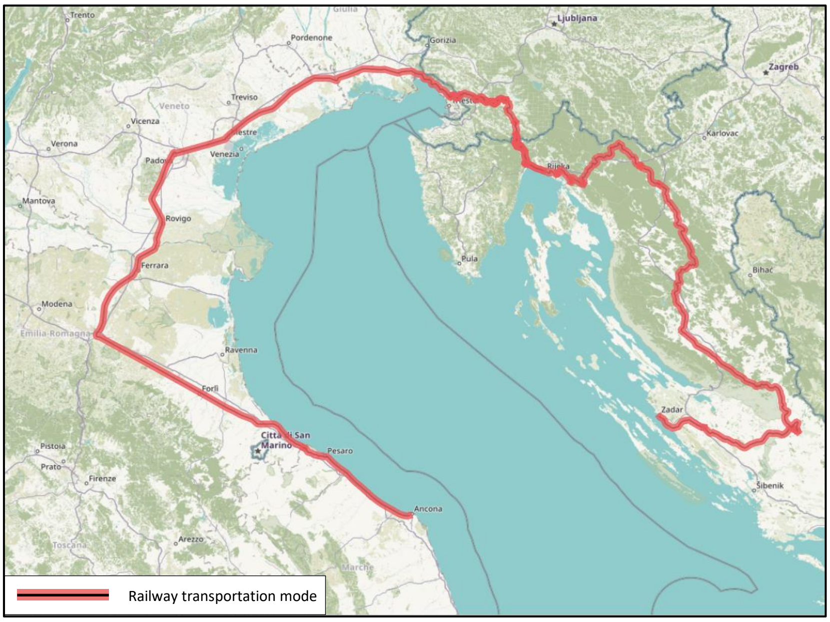



Figure 22. Route Ancona – Zadar (Railway transportation mode)

## 4.4. Case Study 3: Carbon footprint calculation for Dubrovnik – Bari route

Dubrovnik – Bari route is chosen as a single route located in the Southern Adriatic region. On this route, the distances distribution between the different transportation modes is larger than on any other selected route.

The port of Dubrovnik is located in southern Croatia, and accordingly, in the Southern Adriatic region. Moreover, the port of Dubrovnik is one of the most prominent passenger ports and tourist destinations in the Mediterranean area. The port of Bari is located in the Southern Adriatic region on the Italian coast. These ports serve as the actual origin/destination points on the considered passenger line. The passenger line for which the ports mentioned above present origins or destinations is listed in Table 14.

Table 14. Passenger lines serviced in 2019 for the existing Dubrovnik – Bari route

| Passenger line (Line operator) | Vessel name | Average passenger occupancy per trip in 2019 | Number of vessel voyages in 2019 |
|---|---|---|---|
| Dubrovnik – Bari (Jadrolinija) | Dubrovnik | 30.5% | 87 voyages |

For the maritime transportation mode choice, the vessel “Dubrovnik” (IMO Number: 7615048) with 9,795 GT, passenger capacity of 1,300, and vehicle capacity of 300 is used as a reference vessel based on which carbon footprint calculation is conducted. The technical characteristics of the reference vessel are shown in Table 15.

Table 15. Technical characteristics of the reference vessel “Dubrovnik”

| Technical characteristics: Vessel “Dubrovnik” | |
|---|---|
| Vessel type | Ro-PAX Ferry |
| Summer DWT | 1,310 t |
| LOA (Length over all) | 113.01 m |
| Breadth | 18.5 m |
| Draught | 4.83 m |
| Propulsion type | 2x CPP propellers |
| Propulsion power | 13,248 kW |

The carbon footprint calculation for the road transportation mode choice consists of traveling on motorways and highways from Bari to Ploče and continuation by the local roads. Reaching the final destination by road requires a border crossing through Bosnia and Herzegovina, which can negatively impact travel time but not the carbon footprint value. On this route, the railway transportation mode allows transportation between Bari and Split. The distance from Split to Dubrovnik and vice versa must be covered by personal car or public bus. Between two different railways route options, the one via Rijeka (Bari – Ancona – Bologna – Venice – Trieste – Rijeka – Bosiljevo – Zadar – Split – Dubrovnik) and the one via Zagreb (Bari – Ancona – Bologna – Venice – Trieste – Ljubljana – Zagreb – Bosiljevo – Zadar – Split – Ploče – Dubrovnik), the first one is selected for calculation based on the defined shortest path principle.

The total distance determined for Dubrovnik – Bari route is shown in Table 16.

Table 16. Determined distances on the selected Dubrovnik – Bari route

| Route | Maritime transportation mode choice (Nm) | | | Road transportation mode choice (km) | | | Railway-Road transportation mode choice (km) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maneuver | Sea passage | Total | Road | Maritime | Total | Railway (nonel./el.) | Road | Total |
| Dubrovnik – Bari | 4.5 | 104.4 | 108.9 | 1,633 | 0 | 1,633 | 326.9/1,175.1 | 228 | 1,730 |

The maritime transportation distances on the route Dubrovnik – Bari (Figure 23), provided in Table 17, are calculated based on the specific navigation modes taking into account the port features.

Table 17. Distances in the specific navigation modes on the route Dubrovnik – Bari

| | | |
|---|---|---|
| **Route: Dubrovnik – Bari** | Maneuvring on departure | 2.1 Nm |
| | Sea passage | 104.4 Nm |
| | Maneuvring on arrival | 2.4 Nm |

Based on 2019 operational timetables, the average vessels speed on the above-mentioned route is assumed to be 11.6 kn.

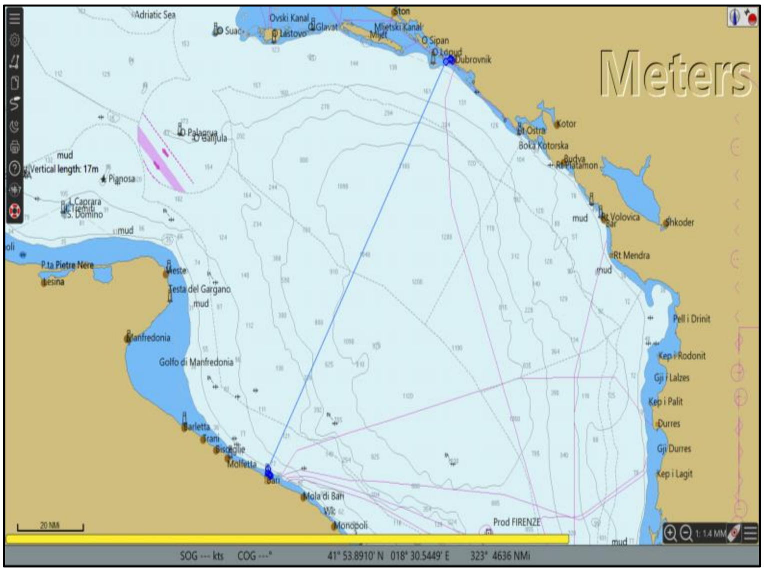



Figure 23. Route Dubrovnik – Bari (Maritime transportation mode)

The personal car and public bus transport mode for the selected route (Figure 24) consists of traveling on the following road segments:

- Italy: motorways A14 (part of European route E55), A13, A4, and highway SS14 – from Bari to Bologna, from Bologna to Padua, from Padua to Trieste, and from Trieste to border crossing Krvavi Potok, respectively,
- Slovenia: state road G7- from border crossing Krvavi Potok to Starod,
- Croatia: highway D8, motorways A7, A6, A1, highways D425, and D8 – from border crossing Pasjak to border crossing Rupa, from border crossing Rupa to Orehovica, from Orehovica to junction Bosiljevo, from junction Bosiljevo to junction Karamatići, from junction Karamatići to Ploče, from Ploče to border crossing Klek-Neum I, respectively,
- Bosnia and Herzegovina: highway M2 – from border crossing Klek-Neum I to Neum II,
- Croatia: highway D8 – from border crossing Neum II to the port of Dubrovnik.

The total calculated road distance for the mentioned route is 1,633 km.

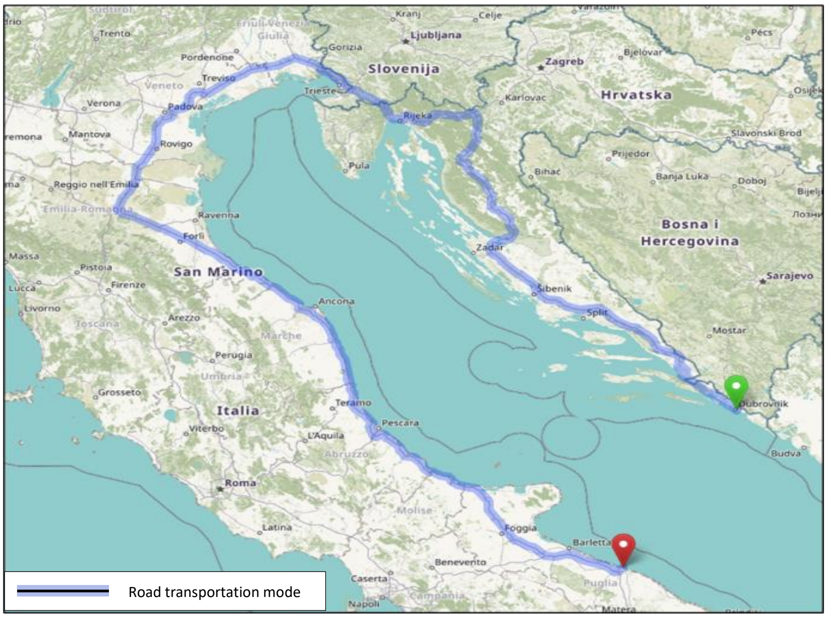



Figure 24. Route Dubrovnik – Bari (Road transportation mode)

The railway transportation mode for the Dubrovnik – Bari route consists of several sections (Figure 25). The first two route sections are located in Italy (Bari – Bologna, and Bologna – Venice – Trieste – Villa Opičina), with a total distance of 958.9 km. The sections in Slovenia (Villa Opičina –Divača – Pivka and Pivka – Šapjane) cover a total distance of 68.6 km. The last railway sections are located in Croatia. The first section is an electrified one (Šapjane – Rijeka – Ogulin) with the distance of 147.5

km, and the second is non-electrified (Ogulin – Knin – Perković – Split) with the total distance of 326 km. As already mentioned, the last section of the route with a distance of 228 km (Split – Dubrovnik) is assumed that is covered by public bus transport mode due to non-existence of railway infrastructure. Bus capacity for carbon footprint is adjusted and assumed to be the same as train capacity (209 pax ⇒ approx. 4 buses). The total calculated distance used in the carbon footprint calculation for this route is 1,729.9 km.


Figure 25. Route Dubrovnik – Bari (Railway transportation mode)

## 4.5. Case Study 4: Carbon footprint calculation for Pesaro – Novalja – Mali Lošinj route

Pesaro – Novalja – Mali Lošinj – Pesaro route is a non-existing passenger line determined by combining several existing passenger lines. The mentioned route is classified as a closed circled route located in the Northern Adriatic region. The mentioned route consists of several destinations located on the islands of Pag and Mali Lošinj. Therefore, the route is segmented into three major segments: Pesaro – Mali Lošinj, Mali Lošinj – Novalja, and Novalja – Pesaro. This route is specific due to the possibility of using multimodal transport.

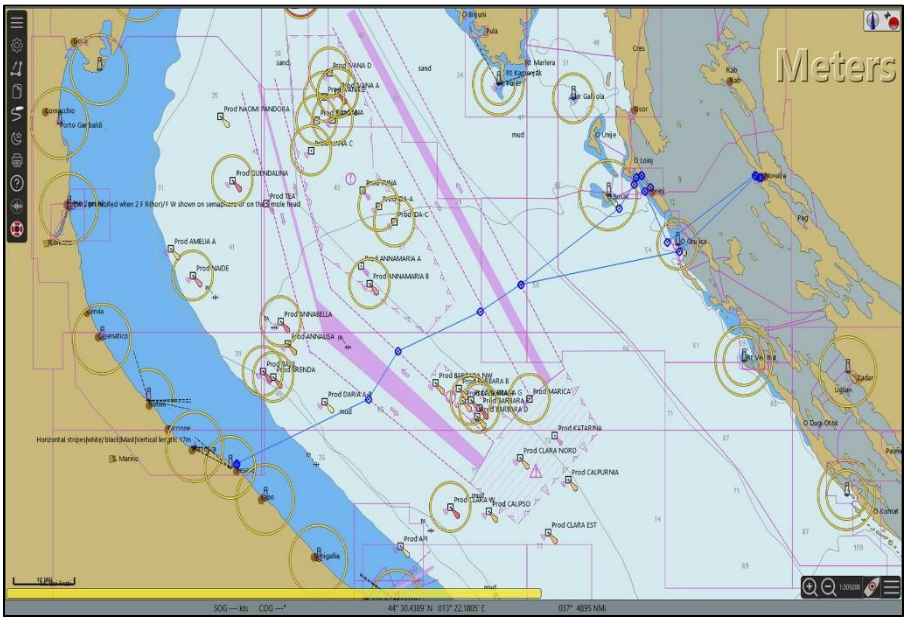



Figure 26. Route Pesaro – Novalja – Mali Lošinj (Maritime transportation mode)

The port of Pesaro is located on the northeastern part of the Italian mainland as a port in the Northern Adriatic region. The port serves as a base for the existing passenger lines to/from Croatia. The port of Novalja is located in the northern part of the island of Pag in the Northern region of the Adriatic Sea. Its primary purpose is to serve local fishing vessels, pleasure crafts, and domestic ferries.

The port of Mali Lošinj is located on the island of Lošinj in the Northern region of the Adriatic Sea. The port serves existing local passenger lines in Croatia.

The passenger line for which the ports mentioned above present origins or destinations are listed in Table 18.

Table 18. Passenger lines serviced in 2019 for the existing Cesenatico – Rab route

| Existing passenger lines (Line operator) | Vessel name | Average passenger occupancy per trip in 2019 | Number of vessel voyages in 2019 |
|---|---|---|---|
| **Cesenatico – Pesaro – Mali Lošinj – Novalja – Rab** (Multi Services Group) | Nautilus | 24.9% | 60 voyages |

For the maritime transportation mode choice, the vessel "Nautilus" (IMO Number: 9017575) with 391 GT and passenger capacity of 400 is used as a reference vessel based on which carbon footprint calculation is conducted. The technical characteristics of the reference vessel are shown in Table 19.

Table 19. Technical characteristics of the reference vessel "Nautilus"

| **Technical characteristics: Vessel "Nautilus"** | |
|---|---|
| Vessel type | HSC single-hull |
| Summer DWT | 42 t |
| LOA (Length over all) | 47 m |
| Breadth | 7.6 m |
| Draught | 1.26 m |
| Propulsion type | 2x water jets |
| Propulsion power | 4,000 kW |

The carbon footprint calculation for the road transportation mode choice consists of traveling on motorways, highways, and state roads. Traveling by the railway transportation mode is only possible between Pesaro – Rijeka or Zadar where the personal car or public bus are used to achieve the final destinations.

The total distances determined for Pesaro – Novalja – Mali Lošinj – Pesaro route, i.e., its segments, are shown in Table 20.

Table 20. Determined distances on the selected Pesaro – Novalja – Mali Lošinj – Pesaro route

| Route Segment | Maritime transportation mode choice (Nm) | | | Road transportation mode choice (km) | | | Railway-Road transportation mode choice (km) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maneuver | Sea passage | Total | Road | Maritime | Total | Railway (nonel./el) | Road | Total |
| Novalja – Mali Lošinj | 3.4 | 27.8 | 31.2 | 208 | 10 | 218 | N/A | 208 | N/A |
| Pesaro – Novalja | 2.2 | 93.7 | 95.9 | 638 | 3.1 | 641.1 | 318.3/673.7 | 75.7 | 1067.7 |
| Mali Lošinj – Pesaro | 3.4 | 75.6 | 79 | 623 | 5.1 | 628.1 | 0/553.9 | 124 | 677.9 |

The maritime transportation distances on the route segment Pesaro – Novalja (Figure 27), provided in Table 21, are calculated based on the specific navigation modes taking into account the port features.

Table 21. Distances travelled in the specific navigation modes on the route segment Pesaro –*Novalja*

| | | |
|---|---|---|
| Route segment: Pesaro – Novalja | Maneuvring on departure | 1.2 Nm |
| | Sea passage | 93.7 Nm |
| | Maneuvring on arrival | 1 Nm |

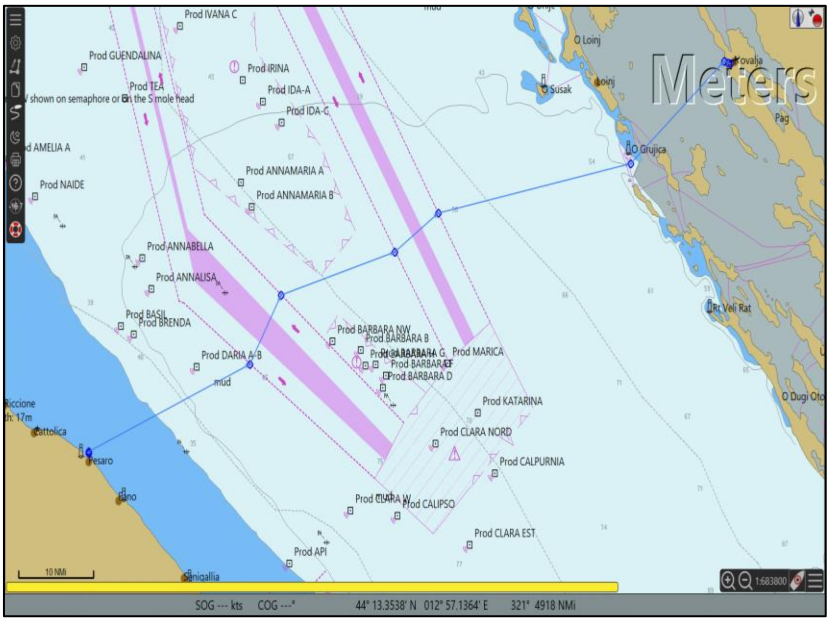



Figure 27. Route segment Pesaro – Novalja (Maritime transportation mode)

The road transportation mode on the Pesaro – Novalja route segment (Figure 28) is realized by personal car or public bus on the following road segments:

- Italy: motorway A14 (part of European route E55), A13, A4, and highway SS14 - from Pesaro to Bologna, from Bologna to Padua, from Padua to Trieste, and from Trieste to border crossing Krvavi Kotok, respectively,
- Slovenia: state road G7 – from border crossing Krvavi Potok to Starod,
- Croatia: highway D8 motorway A7 (part of European route E61), state road D8 (part of European route E61) – from border crossing Pasjak to border crossing Rupa, and from Šmrika to the ferry port Prizna, respectively,
- Croatia: local ferry line “Prizna – Žigljen” – from Prizna to Žigljen, and
- Croatia: state road D106 – from Žigljen to Novalja.

The total calculated road distance for the mentioned route segment is 638 km in addition to 3.1 km, which needs to be covered by the local ferry line.

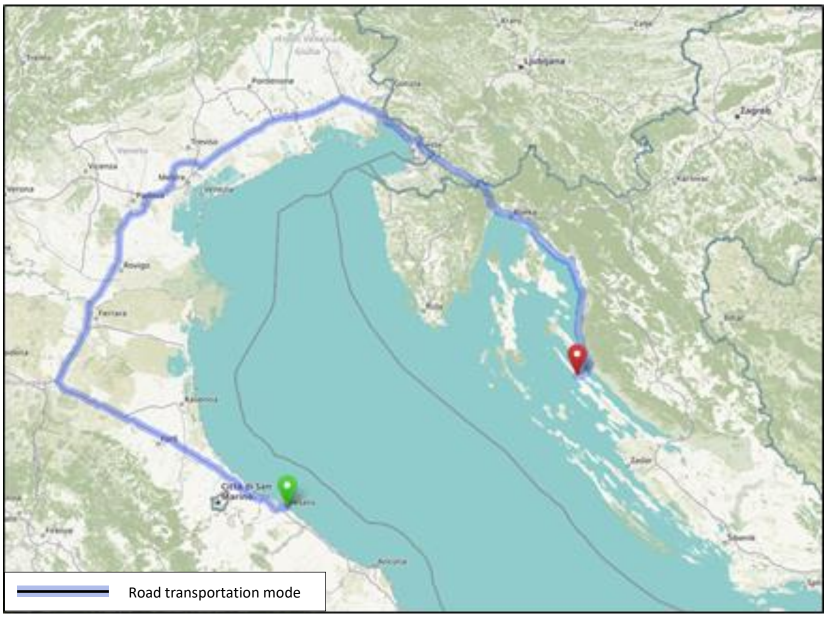



Figure 28. Route segment Pesaro – Novalja (Road transportation mode)

The total distance covered by the railway transportation mode on the Pesaro – Novalja route segment consists of several sections (Figure 29). The first two sections are located in Italy (Pesaro – Bologna, and Bologna – Venice – Trieste – Villa Opičina), electrified railway section with a total distance of 457.6 km. The next section (Villa Opičina – Divača – Pivka, and Pivka – Šapjane) is in Slovenia and involves 68.6 km. The following sections are in Croatia, including the electrified one (Šapjane – Rijeka – Ogulin) with the total distance of 147.4 km and the non-electrified one (Ogulin – Knin – Zadar) with the total distance of 318.3 km. The last section of this route segment (Zadar – Novalja) is assumed to be accomplished by the public bus mode with a total length of 75.7 km. Bus capacity for carbon footprint is adjusted and assumed to be same as train capacity (209 pax ⇒ approx. 4 buses). The total calculated distance used in the carbon footprint calculation for this route is 992.0 km completed by the railway transportation mode and 75.7 km by the road.


Figure 29. Route segment Pesaro – Novalja (Railway transportation mode)

The next route segment Novalja – Mali Lošinj (Figure 30), is based on the actual route (Table 22). This approach compares the possibility of a closed circular route with small distances between two destinations, where one cannot be reached by railway.

Table 22. Distances in the specific navigation modes on the route segment Novalja – Mali Lošinj

| | | |
|---|---|---|
| Route segment: Novalja – Mali Lošinj | Maneuvring on departure | 1.2 Nm |
| | Sea passage | 27.8 Nm |
| | Maneuvring on arrival | 2.2 Nm |

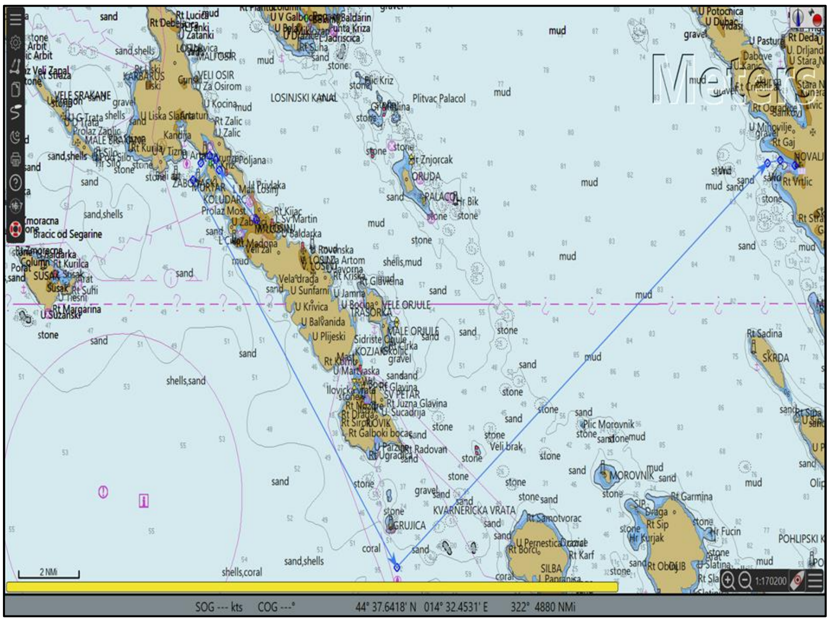



Figure 30. Route segment Novalja – Mali Lošinj (Maritime transportation mode)

The road transportation mode on the Novalja – Mali Lošinj route segment (Figure 31) is realized by personal car or public bus on the following road segments:

- Croatia: state road D106 - from Novalja to Žigljen,
- Croatia: local ferry line “Žigljen – Prizna” – from Žigljen to Prizna,
- Croatia: state road D8 (part of European route E65), D102, D104 - from Prizna to Šmrika, from Šmrika to Valbiska, respectively,
- Croatia: local ferry line “Valbiska – Merag” – from Valbiska to Merag, and
- Croatia: state roads D101, and D100 - from Merag to Mali Lošinj.

The total calculated road distance for the mentioned route segment is 208 km, with the additional 10 km covered by two different local ferry lines.

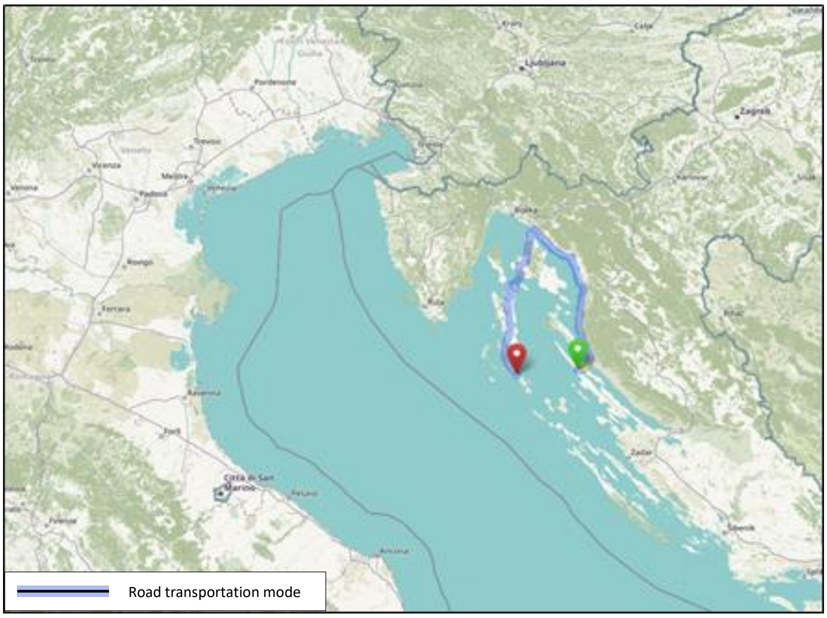



Figure 31. Route segment Novalja – Mali Lošinj (Road transportation mode)

Novalja and Mali Lošinj are not directly accessible by railway. The nearest railway stations are Zadar and Rijeka. As these railway stations are far from the final destinations and since the railway route segment distances are significantly longer than the road route segment, the railway transportation mode in this case is not preferable from practical standpoint. Therefore, the distances and emissions for the railway transportation mode are not calculated.

The route segment Mali Lošinj – Pesaro represents the last segment of this route. The maritime transportation distances on the route segment Mali Lošinj – Pesaro (Figure 32), provided in Table 23, are calculated based on the specific navigation modes considering the specific port features.

Table 23. Distances in the specific navigation modes on the route segment Mali Lošinj – Pesaro

| | | |
|---|---|---|
| | Maneuvering on departure | 2.2 Nm |
| Route segment: Mali Lošinj – Pesaro | Sea passage | 75.6 Nm |
| | Maneuvering on arrival | 1.2 Nm |

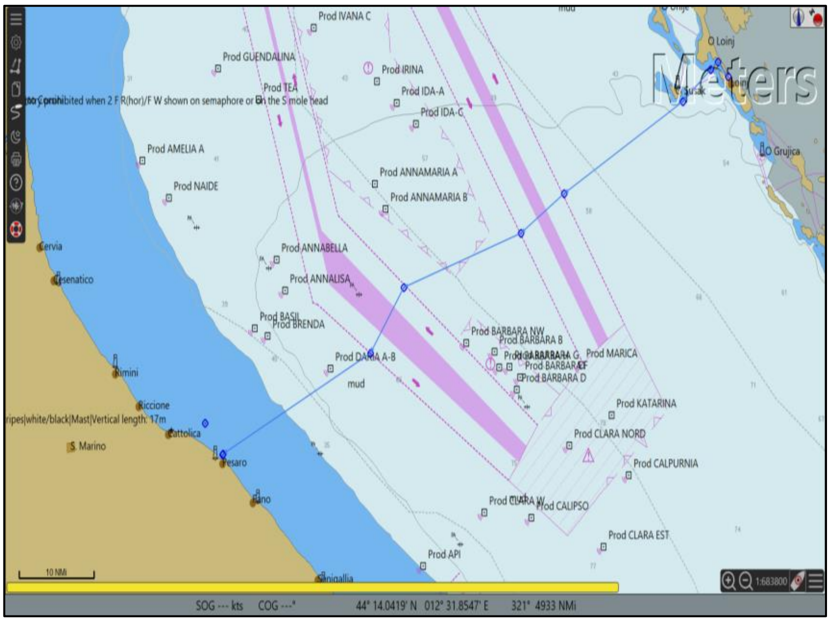



Figure 32. Route segment Mali Lošinj – Pesaro (Maritime transportation mode)

The road transportation mode on the Mali Lošinj – Pesaro route segment (Figure 33) is realized by personal car or public bus on the following road segments:

- Croatia: state road D101 - from Mali Lošinj to Prizna,
- Croatia: local ferry line “Porozina – Brestova” - from Porozina to Brestova,
- Croatia: state roads D66, D500, motorway A8, state roads D44, and D201 - from Brestova to Vozilići, from Vozilići to Veprinac, from Veprinac to Lupoglav, from Sočerga to Caresana, respectively.
- Italy: state road SP13, highway SS202, and motorways SS202, A4, A13, A14 (part of European route E55) - from Caresana to Mattonaia, from Mattonaia to Villa Opičina, from Trieste to Padua, from Padua to Bologna, from Bologna to Pesaro.

The total calculated road distance for the mentioned route segment is 623 km, with additional 5.1 km covered by the local ferry line in Croatia.

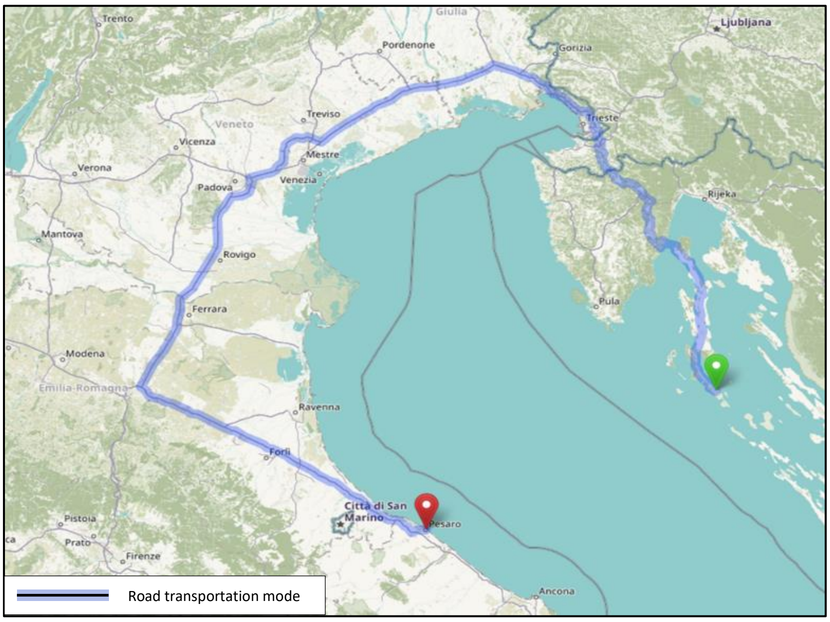



Figure 33. Route segment Mali Lošinj – Pesaro (Road transportation mode)

To reach the destination on the route segment Mali Lošinj – Pesaro (Figure 34), the railway transportation mode involves inevitable support to the public bus and the maritime transportation mode, especially on the first section of the route segment. This includes the following combinations:

- Croatia: state roads D101 and D100 - from Mali Lošinj to ferry port Merag,
- Croatia: local ferry line "Valbiska – Merag" – from Valbiska to Merag,
- Croatia: state roads D104 and D102 - from Valbiska to Šmrika, and
- Croatia: motorway A7 (part of European route E61) - from Šmrika to Rijeka.

The total calculated distance of the above-mentioned road-maritime combination is 131.1 km, where 5.1 refers to traveling by the local ferry line. The following sections of the route segment are covered by an electrified railway in the following order: Rijeka – Šapjane with a calculated total distance of 27.7 km, Šapjane – Pivka – Divača – Villa Opičina with a total distance of 68.6 km, Villa Opičina – Trieste – Venice – Bologna with a total distance of 313.1 km, and the last section of this route segment Bologna – Pesaro with a calculated total distance of 144.4 km. Complete railway route is the electrified one with total distance 677.9 km.


Figure 34. Route segment Mali Lošinj – Pesaro (Railway transportation mode)

## 4.6. Case Study 5: Carbon footprint calculation for Lignano – Grado - Trieste – Mali Lošinj route

Lignano – Grado – Trieste – Mali Lošinj route is chosen as a single route located in the Northern Adriatic region that connects four important passenger transport destinations. From a geographical point of view, all origins/destinations are reachable with various modes of transportation, where travel distances are very similar to each other. The mentioned route is also very important due to the observed attractiveness rate, especially in the season period where Mali Lošinj may represent a central location for every other destination in the Northern Adriatic Region.

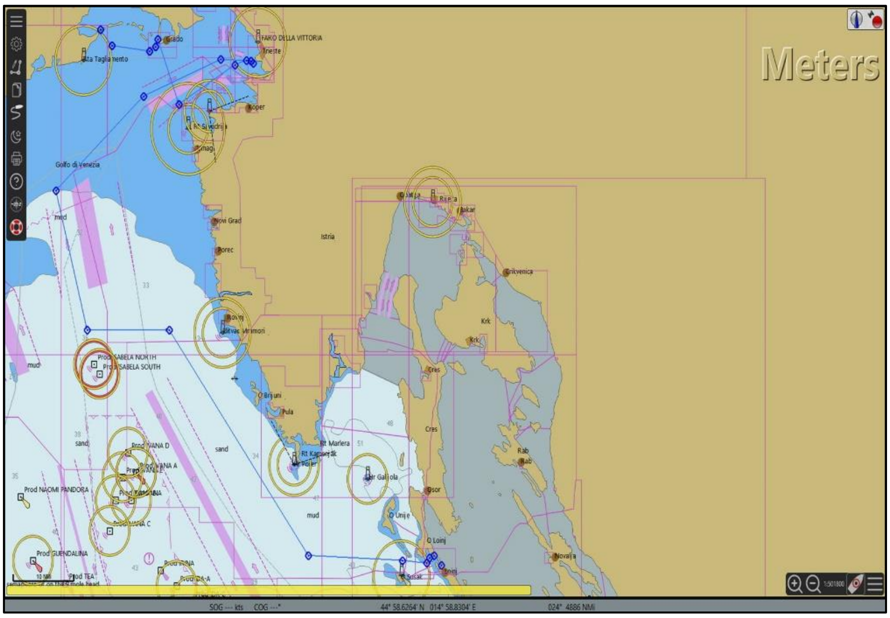



Figure 35. Route Lignano – Grado – Trieste - Mali Lošinj (Maritime transportation mode)

The ports of Lignano and Grado are located in north-eastern Italy in the Northern Adriatic Region. The general purpose of the ports is to handle small pleasure crafts and yachts as well as small fishing vessels, coastal commercial and ferry traffic.

The port of Trieste is located in north-eastern Italy in the Northern Adriatic Region in the Gulf of Trieste. From the perspective of the maritime passenger transportation lines, the port serves as an actual origin/destination of the existing passenger line. The existing last known data on the passenger line for the referent year of 2019 are listed in Table 24. However, Lignano – Grado line was introduced in summer of 2021 and it is established within Interreg MIMOSA project and therefore presented accordingly.

The port of Mali Lošinj is located in the Northern region of the Adriatic Sea. The port has a sheltered harbor and mainly handles local fishing vessels, pleasure crafts, and domestic ferries. From the perspective of maritime passenger transportation lines, the port serves the existing local passenger lines.

Table 24. Passenger lines serviced in 2019* for the existing Lignano - Grado - Trieste – Mali Lošinj route

| **Existing passenger lines (Line operator)** | **Vessel name** | **Average passenger occupancy per trip in 2019*** | **Number of vessel voyages** |
|---|---|---|---|
| Lignano – Grado* (TPL-FVG Scarl) | * | * | * |
| Grado – Trieste (TPL-FVG Scarl) | Delfino Verde Gold | 43.2% | 552 voyages (high season)* |
| Trieste – Piran – Poreč – Rovinj – Mali Lošinj (LibertyLines) | Sofia M | 46.9% | 81 voyages (high season) |

*Line Lignano – Grado was introduced in 2021 (data are for 2021 year)

For the maritime transportation mode choice, on route segment Grado – Trieste the vessel "Delfino Verde Gold" (MMSI Number: 247240700) was employed in 2019 (Table 25) with 24.49 GT and total persons on board capacity of 150.

Table 25. Technical characteristics of the reference vessel "Delfino Verde Gold"

| **Technical characteristics: Vessel "Delfino Verde Gold"** | |
|---|---|
| Vessel type | Motor boat |
| Summer DWT | N/A |
| LOA (Length over all) | 27,2 m |
| Breadth | 6 m |
| Draught | 1,6 |
| Propulsion type | 2x fixed pitch propellers |
| Propulsion power | 125 kW |

For the maritime transportation mode choice, on route segments Trieste – Mali Lošinj the vessel "Sofia M" (IMO Number: 9593634) with 242 GT and passenger capacity of 200 is used as a reference vessel based on which carbon footprint calculation is conducted. The technical characteristics of the reference vessel are shown in Table 26.

Table 26. Technical characteristics of the reference vessel "Sofia M"

| **Technical characteristics: Vessel "Sofia M"** | |
|---|---|
| Vessel type | HSC single hull |
| Summer DWT | 112 t |
| LOA (Length over all) | 37.5 m |
| Breadth | 7 m |
| Draught | 1.54 m |
| Propulsion type | 3x fixed pitch propellers |
| Propulsion power | 3,240 kW |

Furthermore, the road transportation mode consists of taking either personal car or public bus for the Lignano Sabbiadoro to Grado route segment. The next route segment is taking into account the road from Grado to Trieste city centre. Road route from Trieste to Mali Lošinj leading through Slovenia and Croatia cross-border region to reach Istrian peninsula and Port of Porozina. By taking local ferry island of Cres can be reached and furthermore reaching island of Lošinj where final destination is located by local road. The journey to the destination consists of traveling by local roads, highways, and motorways through complete road. Taking railway transportation mode for traveling the distance between these destinations consists of traveling from Latisana-Lignano-Bibione through Cervignano-Aquileia-Grado. By taking this railway route two destinations; Lignano and Grado; can be reached by public road. Furthermore, traveling by train to Trieste Centrale and through Villa Opičina – Divača – Pivka – Šapjane - Rijeka can be reached. Reaching final destination of Mali Lošinj is possible by taking local public bus through island of Krk and Cres to reach island of Lošinj. In that case taking the local ferry from Valbiska to Merag is necessary.

The total distances determined for Lignano – Grado - Trieste – Mali Lošinj route are shown in Table 27.

Table 27. Determined distances on the selected Trieste – Mali Lošinj route

| Route Segment | Maritime transportation mode choice (Nm) | | | Road transportation mode choice (km) | | | Railway-Road transportation mode choice (km) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Maneuver | Sea passage | Total | Road | Maritime | Total | Railway (nonel./el) | Road | Total |
| Lignano – Grado | 1.5 | 11.9 | 13.4 | 60.3 | 0 | 60.3 | 0/28.1 | 34.7 | 62.8 |
| Grado – Trieste | 1.5 | 18.8 | 20.3 | 53.4 | 0 | 53.4 | 0/43.5 | 17.1 | 60.6 |
| Trieste – Mali Lošinj | 3.2 | 104.4 | 107.6 | 186.6 | 5.1 | 191.7 | 0/124.9 | 121.5 | 246.4 |

The maritime transportation distances on the route segment Lignano – Grado (Figure 36), provided in Table 28, are calculated based on the specific navigation modes considering the port features.

Table 28. Distances travelled in the specific navigation modes on the route segment Lignano – *Grado*

| | | |
|---|---|---|
| Route segment: Lignano - Grado | Maneuvring on departure | 1 Nm |
| | Sea passage | 11.9 Nm |
| | Maneuvring on arrival | 0.5 Nm |

Based on 2021 operational timetables, the average vessel speed on the above-mentioned route is assumed to be 13.4 kn.

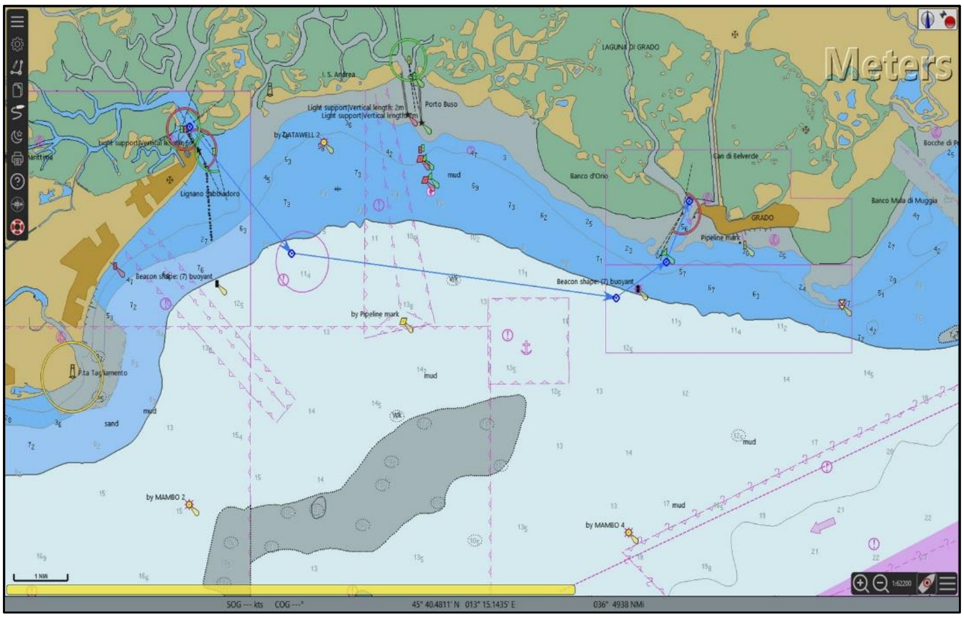



Figure 36. Route segment Lignano – Grado - Trieste (Maritime transportation mode)

The road transportation mode on the Lignano - Grado route (Figure 37) is realized by personal car or public bus on the following road segments:

- Italy: state road SR354, – from Lignano Pineta to Latisana,
- Italy: highway SS14 – from Latisana to Cervignano del Firuli
- Italy: state road SR352 – from Cervignano del Firuli to Grado

The total calculated road distance for the mentioned route is 60.3 km.

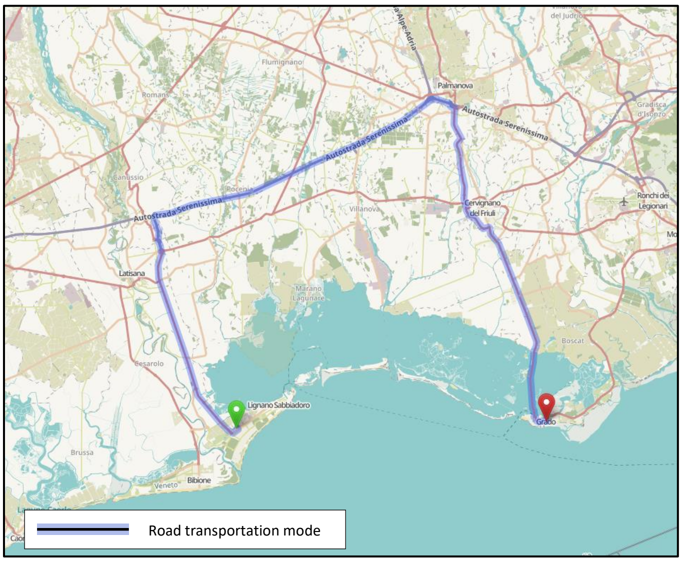



Figure 37. Route segment Lignano – Grado (Road transportation mode)

The railway transportation mode between Lignano and Grado is based on the fact that the route segment from Lignano to Latisana – Lignano – Bibione station must be accomplished by personal car or public bus. The railway transportation mode between Latisana – Lignano – Bibione station through Cervignano – Aquileia – Grado station is to be covered by train in length of 34.7 km (Figure 38). Last part of the voyage needs to be covered by public bus from Cervignano – Aquileia – Grado station to Grado. The complete calculated distance used for carbon footprint calculation is 62,8 km, where 34.7 km must be conducted by the road transportation mode. The complete railway route in this case is electrified.

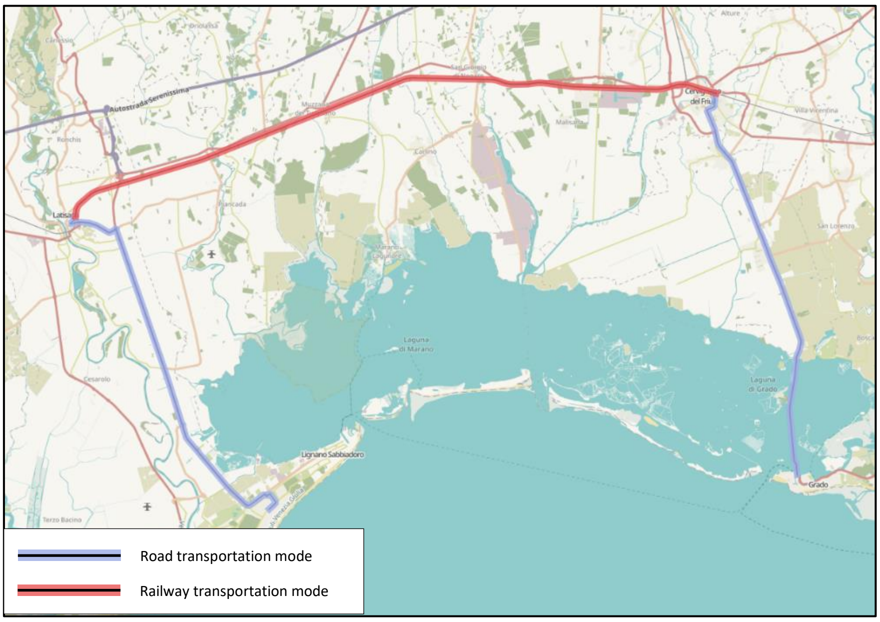



Figure 38. Route segment Lignano – Grado (Railway transportation mode)

The maritime transportation distances on the route segment Grado – Trieste (Figure 39), provided in Table 29, are calculated based on the specific navigation modes considering the port features.

Table 29. Distances travelled in the specific navigation modes on the route segment Grado – *Trieste*

| | | |
|---|---|---|
| Route segment: Grado - Trieste | Maneuvring on departure | 0.5 Nm |
| | Sea passage | 18.8 Nm |
| | Maneuvring on arrival | 1 Nm |

Based on 2021 operational timetables, the average vessel speed on the above-mentioned route is assumed to be 16.2 kn.

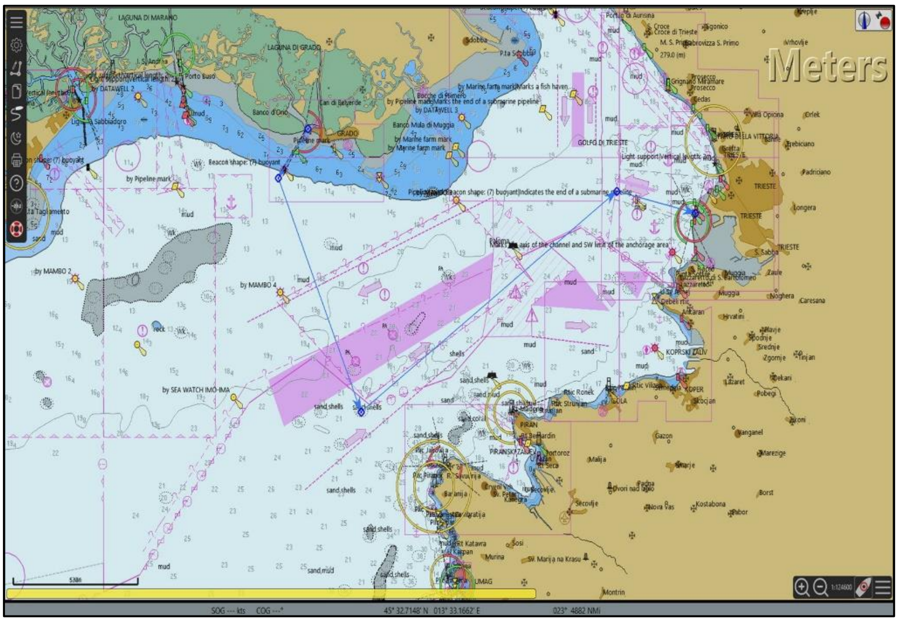



Figure 39. Route segment Grado – Trieste (Maritime transportation mode)

The road transportation mode on the Grado – Trieste route (Figure 40) is realized by personal car or public bus on the following road segments:

- Italy: local road SP14, – from Grado to Monfalcone,
- Italy: highway SS14 and motorway E70 – from Monfalcone to Trieste

The total calculated road distance for the mentioned route is 53.4 km.

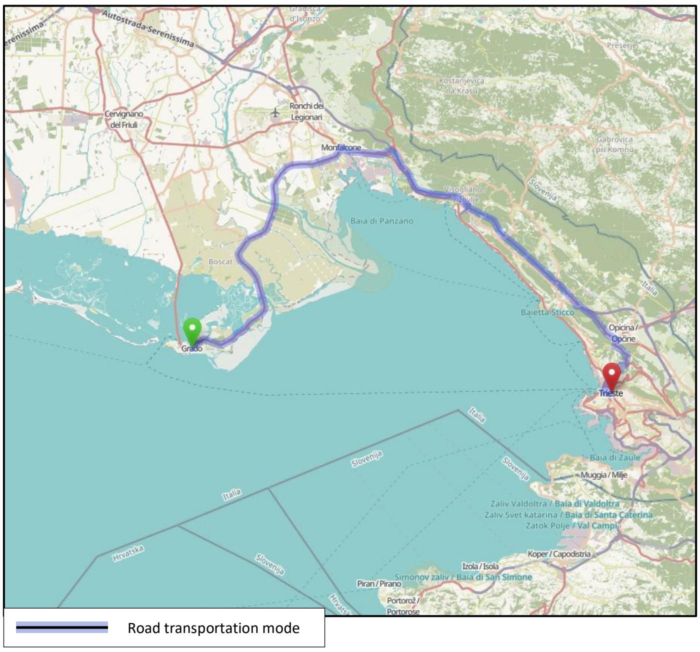



Figure 40. Route segment Grado – Trieste (Road transportation mode)

The railway transportation mode between Grado and Trieste is based on the fact that first route segment from Grado to Cervignano – Aquileia – Grado station must be accomplished by personal car or public bus in length of 17.1 km. The railway transportation mode between Cervignano – Aquileia – Grado station to Trieste Central is to be covered by train in length of 43.7 km (Figure 41). The complete calculated distance used for carbon footprint calculation is 60.6 km, where 17.1 km must be conducted by the road transportation mode. The complete railway route in this case is electrified.


Figure 41. Route segment Grado - Trieste (Railway transportation mode)

The maritime transportation distances on the route segment Trieste – Mali Lošinj (Figure 42), provided in Table 29, are calculated based on the specific navigation modes considering the port features.

Table 30. Distances travelled in the specific navigation modes on the route segment Trieste – Mali *Lošinj*

| | | |
|---|---|---|
| | Maneuvring on departure | 1 Nm |
| Route segment: Trieste – Mali Lošinj | Sea passage | 104.4 Nm |
| | Maneuvring on arrival | 2.2 Nm |

Based on 2019 operational timetables, the average vessel speed on the above-mentioned route is assumed to be 26.7 kn.

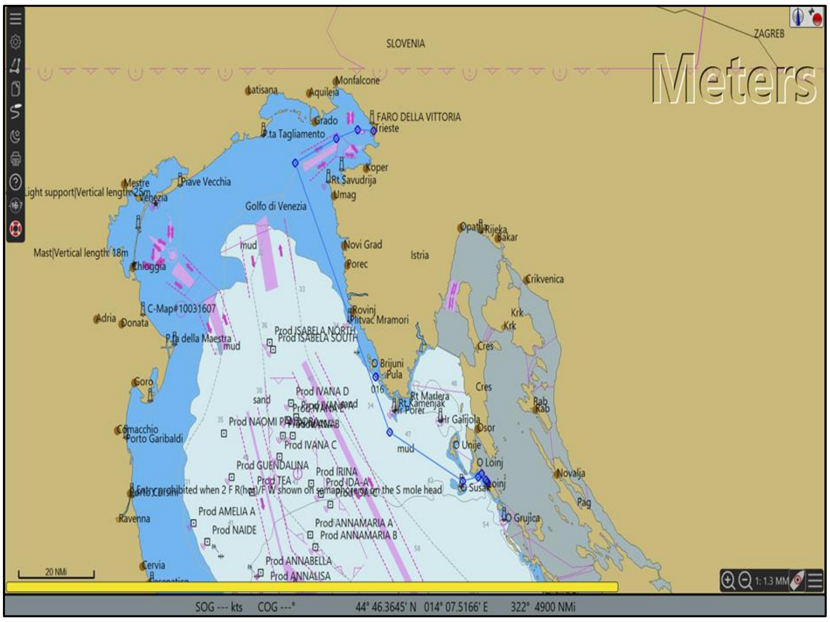



Figure 42. Route segment Trieste – Mali Lošinj (Maritime transportation mode)

The road transportation mode on the Trieste – Mali Lošinj route (Figure 43) is realized by personal car or public bus on the following road segments:

- Italy: highway SS202 – from Trieste to border crossing Škofije,
- Slovenia: highway H5, and state roads 409 and 208 - from border crossing Škofije to border crossing Sočerga,
- Croatia: state roads D201, D44, D500, D66, and D402 - from Sočerga to Brestova,
- Croatia: local ferry line "Brestova – Porozina" – from Brestova to Porozina, and
- Croatia: state roads D100 and D101 - from Porozina to Mali Lošinj.

The total calculated road distance for the mentioned route is 186.6 km, where 5.1 km must be covered by the local ferry line.

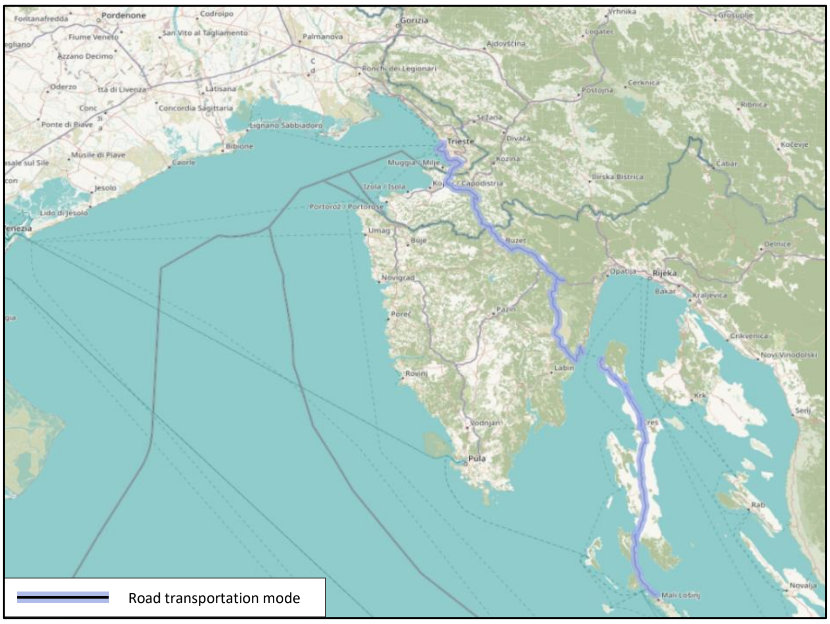



Figure 43. Route segment Trieste – Mali Lošinj (Road transportation mode)

The railway transportation mode between Rijeka and Trieste Centrale is based on the fact that the route segment from Mali Lošinj to Rijeka must be accomplished by personal car or public bus. The railway transportation mode between Trieste and Rijeka consists of several sections (Figure 44). The first section is located in Italy (Trieste Centrale – Villa Opičina), with a total distance of 28.5 km. The following section is in Slovenia (Villa Opičina – Divača – Pivka, and Pivka – Šapjane), with a total distance of 68.6 km. Finally, the last section is in Croatia (Šapjane – Rijeka), with a total distance of 27.7 km. The complete calculated distance used for carbon footprint calculation is 246.3 km, where 121.5 km must be conducted by the road transportation mode. The complete railway route in this case is electrified.

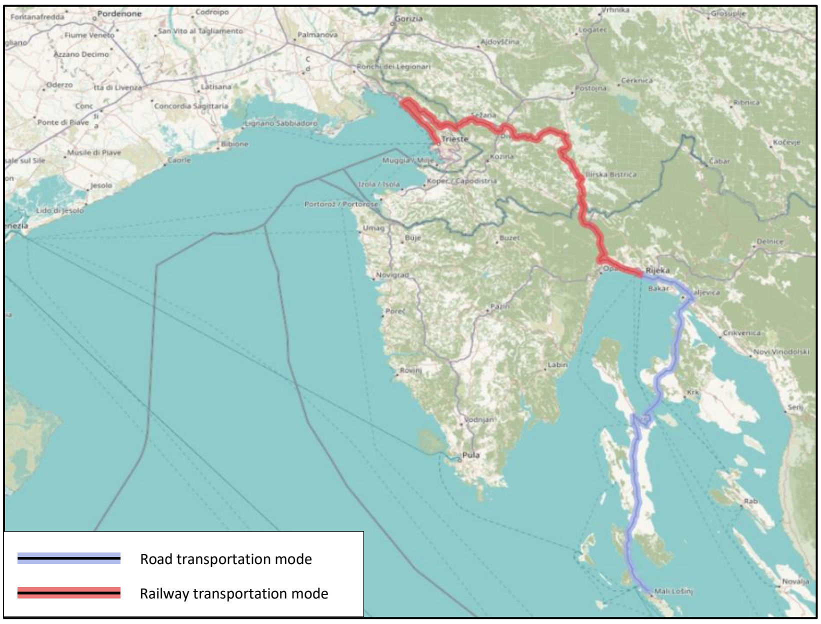



Figure 44. Route segment Trieste – Mali Lošinj (Railway transportation mode)

# 5. Case Studies Results – Evaluation and Comparative Analysis

By implementing the methodology presented in Section 2 and considering the individual routes described in Section 3, the calculated carbon footprint in kgCO2/trip-passenger is presented as a function of the occupancy rates for each transportation mode choice. Occupancy rates are chosen as a relative value for each available transportation mode choice.

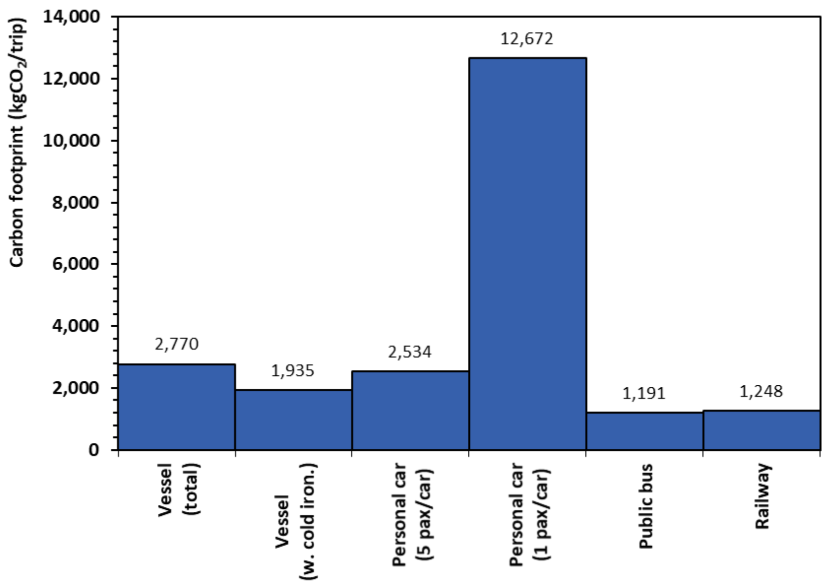
The total carbon footprint in kgCO2 for each transportation mode choice is also calculated based on the reference passenger number. The reference passenger number on each route depends on the technical characteristics of the vessels and their capacities employed on each of the considered route segments. In general, the main objective of interpreting the following results is to present:

- the calculated carbon footprint values per passenger considering different transportation mode choices,
- optimal transportation mode choice with respect to the different relative occupancy rates,
- the total carbon footprint for each transportation mode based on the reference capacity.

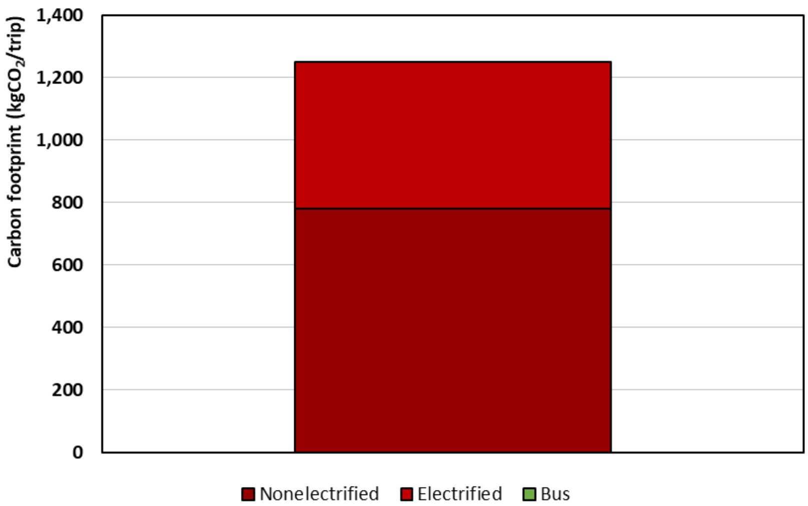
## 5.1. Case study 1 – Venice – Pula – Poreč – Venice Results and Discussion

In this section, the carbon footprint calculation for the route Venice – Pula – Poreč – Venice is considered. This route was divided into three interconnected segments. The first segment is Venice – Pula, the second segment is Pula – Poreč, and the last is Poreč – Venice. Further analysis of the calculated results will be based on these segments.

According to the calculated carbon footprint for the first segment of the route presented in Figure 45a, and for the reference capacity of 330 passengers, the calculated carbon footprint for the maritime transportation mode is 2,770 kg$CO_2$ per trip which includes port stay carbon footprint. In case that the vessel is on cold ironing during port stays, carbon footprint is considerably lower (1,935 kg$CO_2$ per trip). If technical conditions in ports and vessel allows cold ironing to be fully implemented, the total carbon footprint will be in this case lower for approximately 30%. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 12,672 kg$CO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 2,534 kg$CO_2$ per trip. This value is slightly lower than the one of the maritime transportation mode considering that cold ironing is not implemented. However, if the public buses employed on this route segment are fully occupied in regards to reference capacity (330 passengers), a significantly lower carbon footprint of 1,191 kg$CO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 1,248 kg$CO_2$ per trip. This value considers two trains required to transport reference capacity of 330 passengers and is achieved by traveling both on non-electrified and electrified railway sections as presented in Figure 45b.




(a)




(b)

Figure 45. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment Venice – Pula); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Venice – Pula).

According to the results presented in Figure 46, the maritime transportation mode choice without considering cold ironing was identified as the one with the highest carbon footprint value in accordance with the reference capacity. In case that cold ironing is taken into consideration, the maritime transportation mode is more favourable than personal car transportation mode. On the other hand, the lowest calculated carbon footprint value is associated with railway transportation mode choice. Moreover, personal car mode choice is slightly more acceptable than maritime transport without considering cold ironing. Since the curves are relatively close to each other, the difference in relative occupancy rates is the key determinant of the appropriateness of choosing a particular mode of travel in terms of the carbon footprint impact.

However, if the railway transportation mode is taken as a reference, as the most favorable transport mode, the conclusion can be drawn that above a relative occupancy of 84% (total of 277 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 3.5 $kgCO_2$/trip-passenger).

According to Figure 46, if the worst calculated carbon footprint value for railway transportation mode choice (a relative occupancy of 20%, generating 14.93 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents equivalent to the public bus being occupied 24% (12 passengers per public bus), maritime transportation mode being occupied 40% (total of 132 passengers) when cold ironing is considered, personal car 50% (total of 3 passengers per car), and 58% (total of 191 passengers) for maritime transportation mode when cold ironing is not implemented. Above those relative occupancy rates, later mentioned transportation modes will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the maritime transportation mode is considered as the least favorable transportation mode, if the relative occupancy rate is 100% (330 passengers), it can be concluded that the personal car needs to be occupied less than 95% (5 passengers) to be less favorable. Moreover, the public bus transportation mode choice needs to be occupied less than 42% (total of 28 passengers per public bus), and the railway transportation mode less than 38% (total of 125 passengers) to be less favorable than the maritime transportation mode.

The presented approach can be used in this context for further analysis and/or discussion concerning the different setups or requirements.

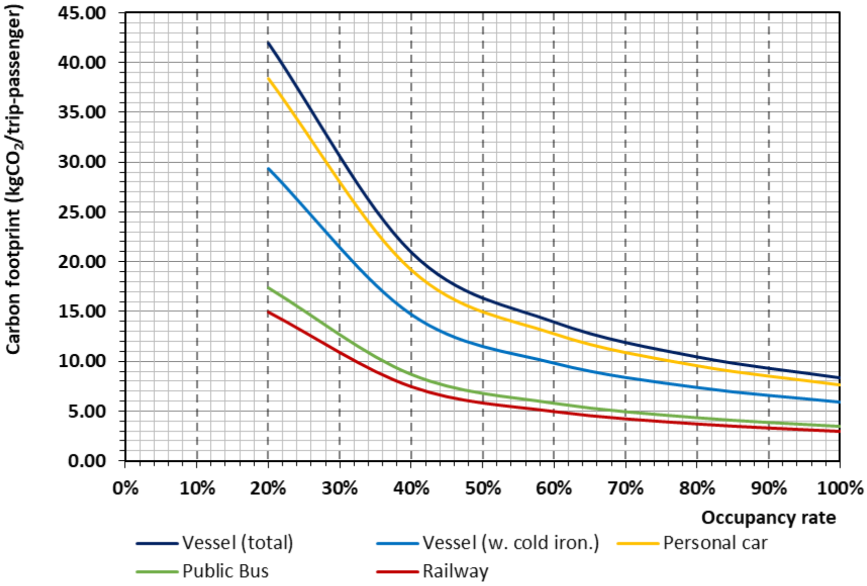
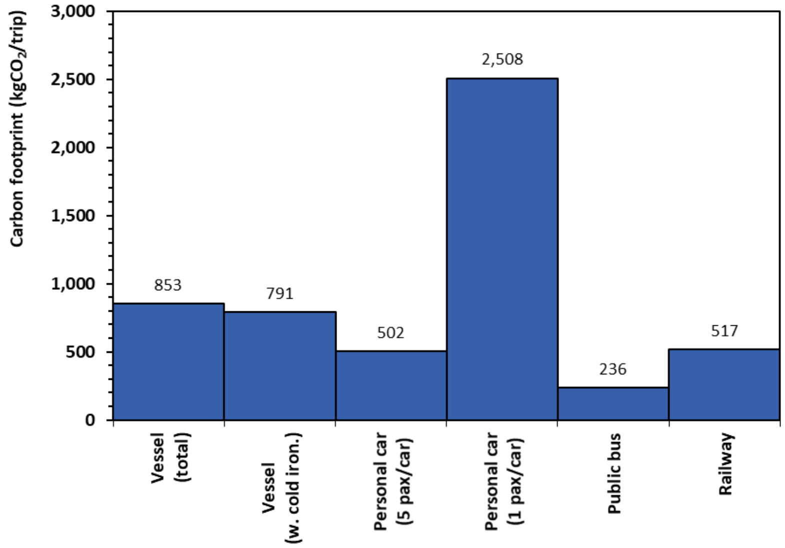
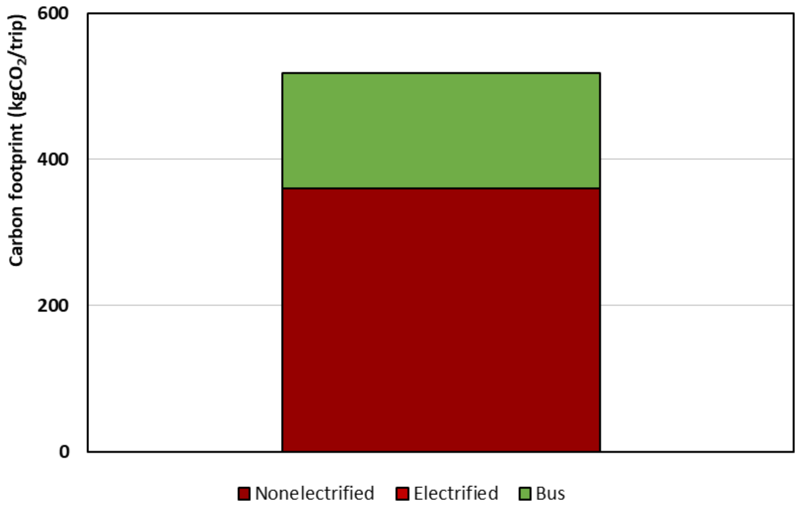



Figure 46. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Venice – Pula

According to the calculated carbon footprint for the second segment of the route presented in the Figure 47a, and for the reference capacity of 330 passengers, the calculated carbon footprint for the maritime transportation mode is 853 $kgCO_2$ per trip which includes port stay carbon footprint. In case that the vessel is on cold ironing during port stays, carbon footprint is lower (791 $kgCO_2$ per trip). If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 2,508 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 502 $kgCO_2$ per trip. This value is considerably lower than the one of the maritime transportation mode. However, if the public buses employed on this route segment are 100% occupied a significantly lower carbon footprint of 236 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 517 $kgCO_2$ per trip. This number is higher than the one obtained for public bus transportation mode based on the same capacity. As this segment requires the integration with the public bus, the calculated carbon footprint value includes the additional value of the carbon footprint calculated for a journey taken by a public bus on the relation Pazin – Poreč as presented in Figure 47b.




(**a**)




(**b**)

Figure 47. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment Pula – Poreč); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Pula – Poreč).

According to the results presented in Figure 48, the maritime transportation mode choice without considering cold ironing was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with public bus transport. Moreover, railway transportation mode choice is slightly more acceptable than personal car mode choice.

However, if the public bus transportation mode is taken as a reference, as the most favorable transport mode, the conclusion can be drawn that above a relative occupancy of 55% (25 passengers per public bus), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 1.5 $kgCO_2$/trip-passenger).

According to Figure 48, if the worst calculated carbon footprint value for public bus mode choice (a relative occupancy of 20%, generating 3.43 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents equivalent to the railway transportation mode being occupied 37% (total of 122 passengers) or personal car being occupied 44% (2 passengers per personal car). Above those relative occupancy rates, railway and personal car transportation modes will offer more acceptable carbon footprint values. Considering that the distances between destinations are short, the differences in the calculated carbon footprint values between personal car and railway transportation modes are not very significant at similar occupancy rates.

On the other hand, under the assumption that, assuming full capacity for all modes, the maritime transportation mode is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (330 passengers), it can be concluded that the railway transportation mode needs to be occupied less than 45% (total of 149 passengers) to be less favourable. Moreover, the personal car mode choice needs to be occupied less than 57% (3 passengers per car), and the public bus less than 28% (14 passengers per public bus) to be less favourable than the maritime transportation mode.

The presented approach can be used in this context for further analysis and/or discussion concerning the different setups or requirements.

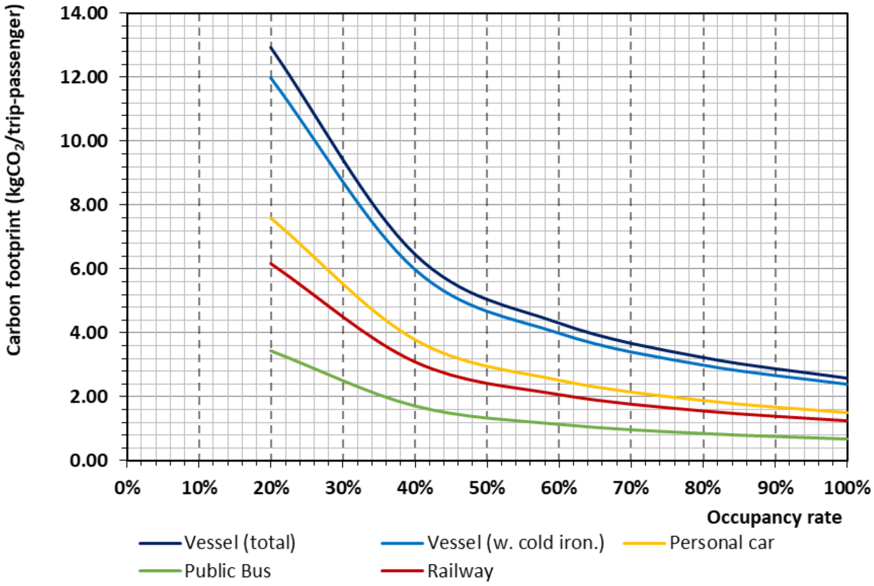
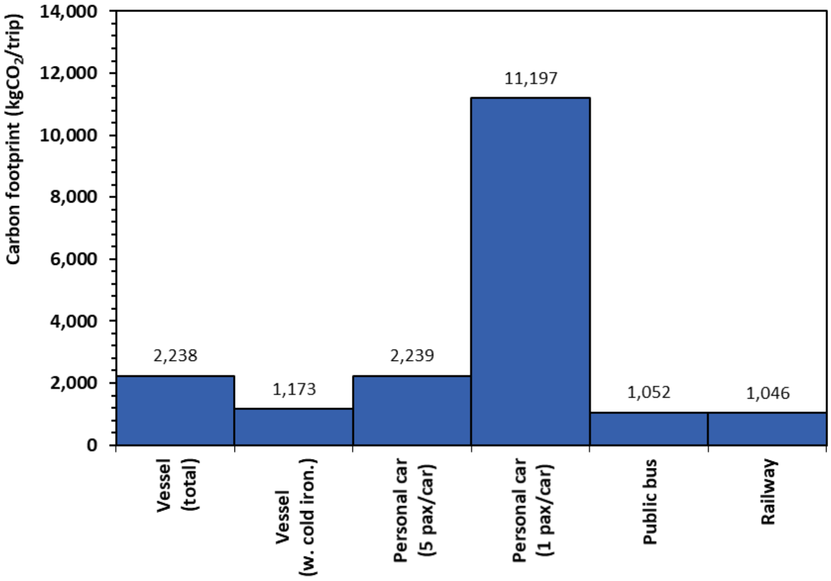
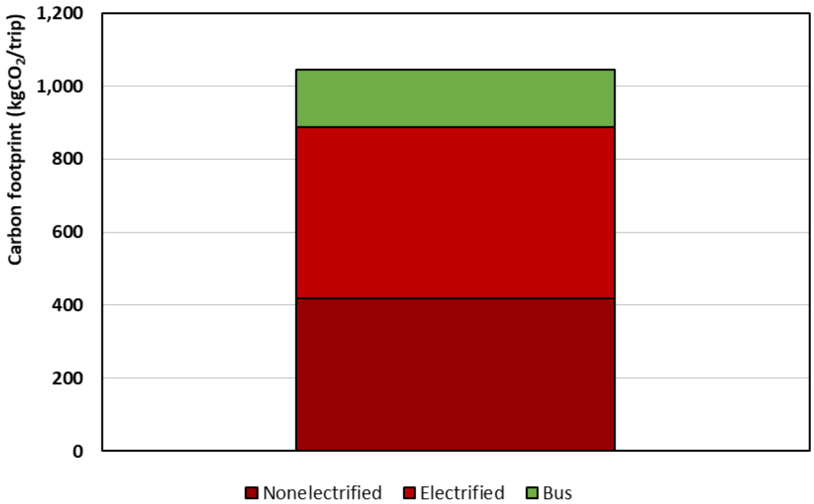



Figure 48. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Pula – Poreč

According to the calculated carbon footprint for the third segment of the route presented in Figure 49a, and for the reference capacity of 330 passengers, the calculated carbon footprint for the maritime transportation mode is 2,238 $kgCO_2$ per trip which includes port stay carbon footprint. In case that the vessel is on cold ironing during port stays, carbon footprint is considerably lower (1,173 $kgCO_2$ per trip). If technical conditions in ports and vessel allows cold ironing to be fully implemented, the total carbon footprint will be in this case lower for approximately 48%. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 11,197 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 2,239 $kgCO_2$ per trip. This value is the same as the carbon footprint value obtained for maritime transportation mode. However, if the public buses employed on this route segment are 100% occupied in regards to reference capacity, a significantly lower carbon footprint of 1,052 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is the lowest with 1,046 $kgCO_2$ per trip. This value considers two trains required to transport reference capacity of 330 passengers and is achieved by traveling both on nonelectrified and electrified railway sections and by buses as well as presented in Figure 49b.




(**a**)




(**b**)

Figure 49. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment Poreč – Venice); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Poreč – Venice)

According to the results presented in Figure 50, the personal car transportation mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. Calculated values for maritime transportation mode where cold ironing is not considered overlaps with personal car transportation mode choice. On the other hand, the lowest calculated carbon footprint value is associated with railway transportation mode. Moreover, the calculated values for the personal car and maritime transportation mode where cold ironing is considered are similar considering the same occupancy rates. Since the curves are relatively close to each other, the difference in relative occupancy rates is the key determinant of the appropriateness of choosing a particular mode of travel in terms of the carbon footprint impact.

However, if the railway transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 75% (total of 248 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 3.7 kg$CO_2$/trip-passenger).

According to Figure 50, if the worst calculated carbon footprint value for public bus mode choice (a relative occupancy of 20%, generating 12.51 kg$CO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the public bus being occupied 27% (14 passengers per public bus) or maritime transportation mode being occupied 32% (106 passengers) when cold ironing is considered, and personal car being occupied more than 55% (3 passengers per personal car). Same occupancy rates apply (55%, 182 passengers) to the maritime transportation mode when cold ironing is not considered. Above those relative occupancy rates for public buses, maritime transportation mode and personal car will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car transportation mode is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (5 passengers per personal car), it can be concluded that the maritime transportation mode needs to be occupied less than 50% (165 passengers) to be less favourable considering that cold ironing is implemented. Moreover, the public bus mode choice needs to be occupied less than 44% (22 passengers per bus), and the railway transportation mode less than 37% (122 passengers) to be less favourable than the personal car transportation mode.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

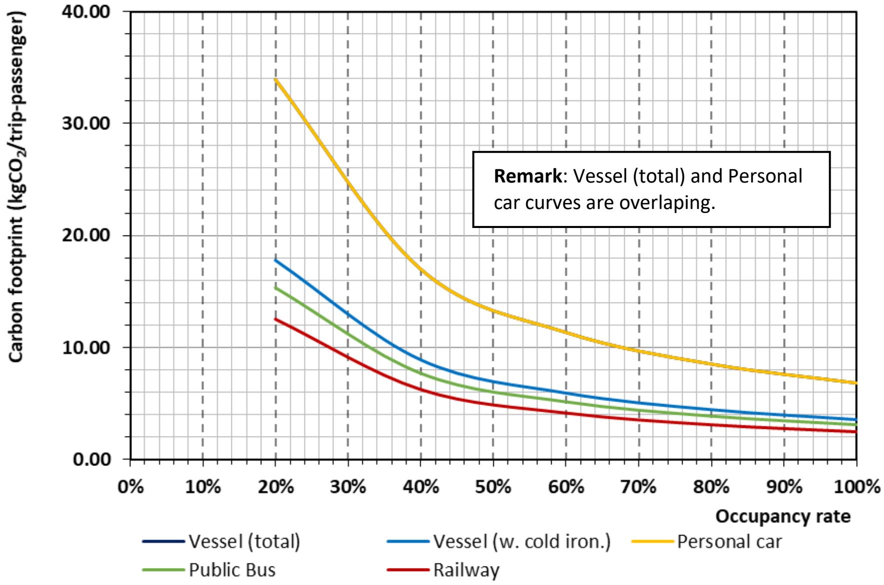
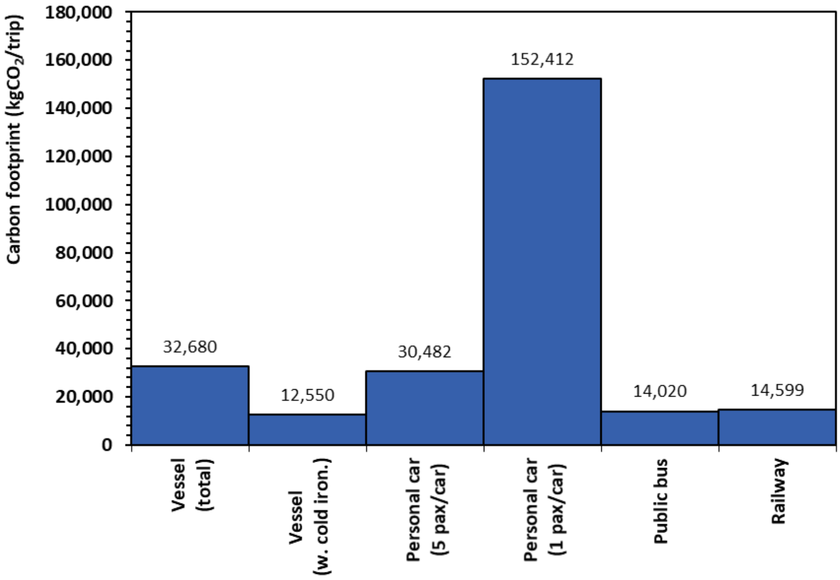



Figure 50. Calculated carbon footprint per trip-pax (kgCO2) for single trip based on occupancy rate for the route segment Poreč – Venice

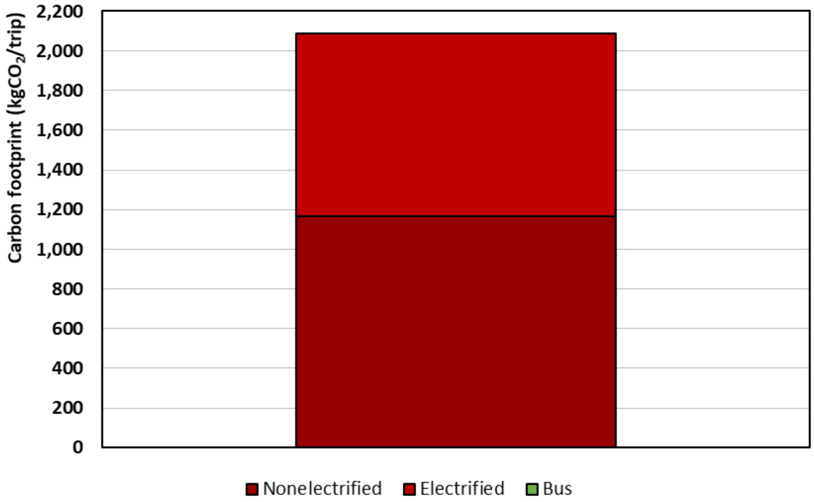
## 5.2. Case study 2 – Ancona – Zadar - Results and Discussion

In this section, the carbon footprint calculation for the route Ancona – Zadar is considered. The mentioned route is a single one, and the return trip is the same as the initial one.

According to the calculated carbon footprint presented in Figure 51a, and for the reference capacity of 1,300 passengers, the calculated carbon footprint for the maritime transportation mode is 32,680 kg$CO_2$ per trip which includes port stay carbon footprint. In case that the vessel carbon footprint during port stay is not considered, carbon footprint is considerably lower (12,550 kg$CO_2$ per trip). Carbon footprint in this case is 60% lower. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 152,412 kg$CO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers per car), the total calculated carbon footprint is 30,482 kg$CO_2$ per trip. This value is slightly lower than the one of the maritime transportation mode considering that port stay carbon footprint is taken into account. However, if the public buses employed on this route are fully occupied in regards to reference capacity (1300 passengers), a significant lower carbon footprint of 14,020 kg$CO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 14,599 kg$CO_2$ per trip. This value considers usage of seven trains required to transport the reference capacity of 1300 passengers and is achieved by traveling both on nonelectrified and electrified railway sections as presented in Figure 51b.




(a)




(b)

Figure 51. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 1,300 passengers (Route segment Ancona – Zadar); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Ancona – Zadar)

According to the calculated carbon footprint for this route (Figure 52), the maritime transportation mode choice with considering port stay emissions was identified as the one with the highest carbon footprint value in accordance with the reference capacity. In case that port stay emissions are not considered, the maritime transportation mode is then the most favourable one. Moreover, personal car mode choice is slightly more acceptable than maritime transport when port stay emissions are considered. Since the curves are relatively close to each other, the difference in relative occupancy rates is the key determinant of the appropriateness of choosing a particular mode of travel in terms of the carbon footprint impact.

However, in this particular case, the carbon footprint for the maritime transportation mode without port stay emissions, public bus transportation mode and railway transportation modes show similar carbon footprint for the reference capacity and present the most favourable transport modes. In this case the conclusion can be drawn that above a relative occupancy of 40% (20 passengers per bus and total of 520 passengers for maritime and railway transportation modes), personal car transportation mode choice cannot deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 23.4 kg$CO_2$/trip-passenger).

According to Figure 52. if the worst calculated carbon footprint value for maritime transportation mode choice when port stay emission is not considered (a relative occupancy of 20%, generating 48,27 kg$CO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the personal car being occupied 48% (3 passengers per car). Above those relative occupancy rates, personal car offers more acceptable carbon footprint values.

On the other hand, under the assumption that the maritime transportation mode when port stay emissions is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (1,300 passengers), it can be concluded that the public bus transportation mode needs to be occupied less than 42% (total of 28 passengers per bus) to be less favourable.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

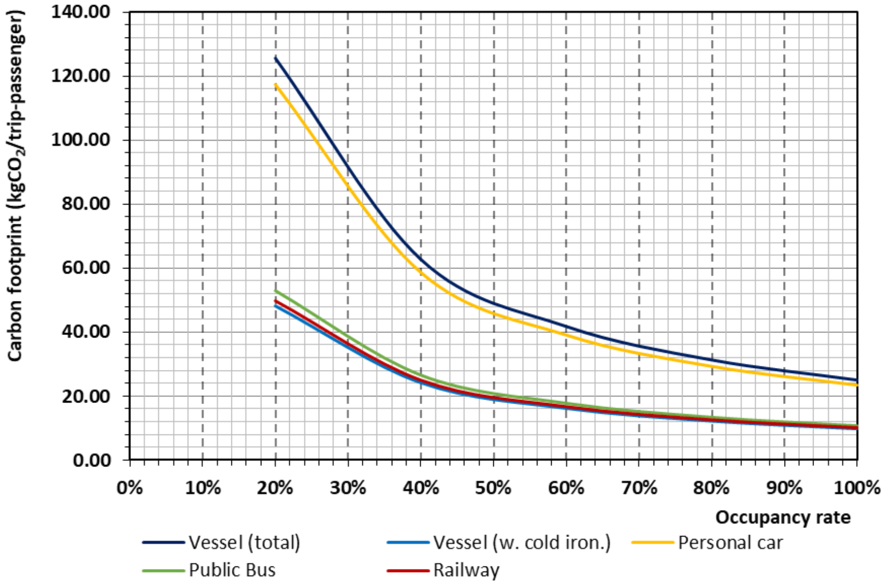
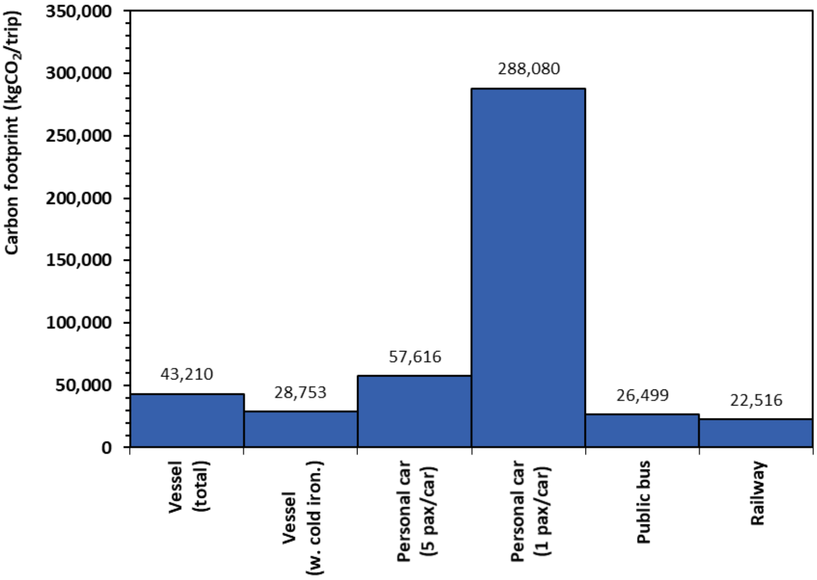



Figure 52. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route Ancona – Zadar

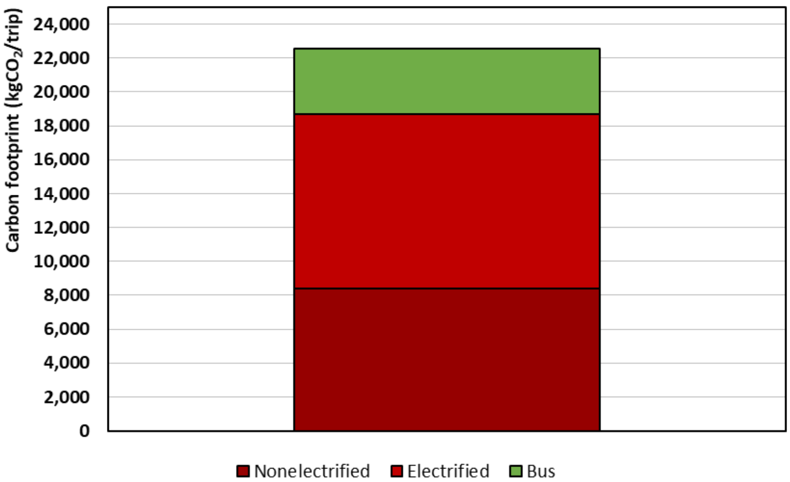
## 5.3. Case study 3 – Dubrovnik – Bari - Results and Discussion

In this section, the carbon footprint calculation for the route the Dubrovnik – Bari is considered. The mentioned route is a single one and the return trip is the same as the initial one.

According to the calculated carbon footprint presented in Figure 53a, and for the reference capacity of 1,300 passengers, the calculated carbon footprint for the maritime transportation mode is 43,210 $kgCO_2$ per trip which includes port stay carbon footprint. In case that the vessel carbon footprint during port stay is not considered, carbon footprint is considerably lower (28,753 $kgCO_2$ per trip). Carbon footprint in this case is 33% lower. If the same number of passengers are transported by personal cars, the calculated carbon footprint is considerably higher: 288,080 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers per car), the total calculated carbon footprint is 57,616 $kgCO_2$ per trip. This value is higher than the one of the maritime transportation mode considering that port stay carbon footprint is taken into account. However, if the public buses employed on this route are fully occupied in regards to reference capacity (1300 passengers), a significant lower carbon footprint of 26,499 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 22,516 $kgCO_2$ per trip. This value considers usage of seven trains required to transport reference capacity and is achieved by traveling both on nonelectrified, electrified railway sections and public buses as well as presented in Figure 53b.




(a)




(b)

Figure 53. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 1,300 passengers (Route segment Dubrovnik - Bari); (b) Carbon footprint for railway transportation mode based on railway section features (Route Dubrovnik – Bari).

According to the calculated carbon footprint presented in Figure 54, the personal car transportation mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with railway transportation mode choice. Moreover, maritime transportation mode choice (both with included and excluded calculated port stay emission) is more acceptable than personal car mode choice.

However, if the railway transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 73% (total of 949 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 20 $kgCO_2$/trip-passenger.

According to Figure 54, if the worst calculated carbon footprint value for railway transportation mode choice (a relative occupancy of 20%, generating 76.95 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the public bus transportation mode being occupied 28% (14 passengers per public bus), maritime transportation mode (without port stay carbon footprint) being occupied 32% (390 passengers), maritime transportation mode (with port stay carbon footprint included) being occupied 43% (559 passengers) or personal car being occupied 58% which represents 3 passengers per car. Above those relative occupancy rates, public bus, maritime transportation mode, and personal car transportation modes will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car transportation mode is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (1,300 passengers), it can be concluded that the maritime transportation mode (port stay carbon footprint included) needs to be occupied less than 75% (975 passengers) to be less favourable. Moreover, the maritime transportation mode (port stay carbon footprint excluded) needs to be occupied less than 48% (624 passengers), public bus less than 44% (22 passengers per public bus), and railway transportation mode choice 36% (total of 468 passengers) to be less favourable than the personal car transportation mode.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

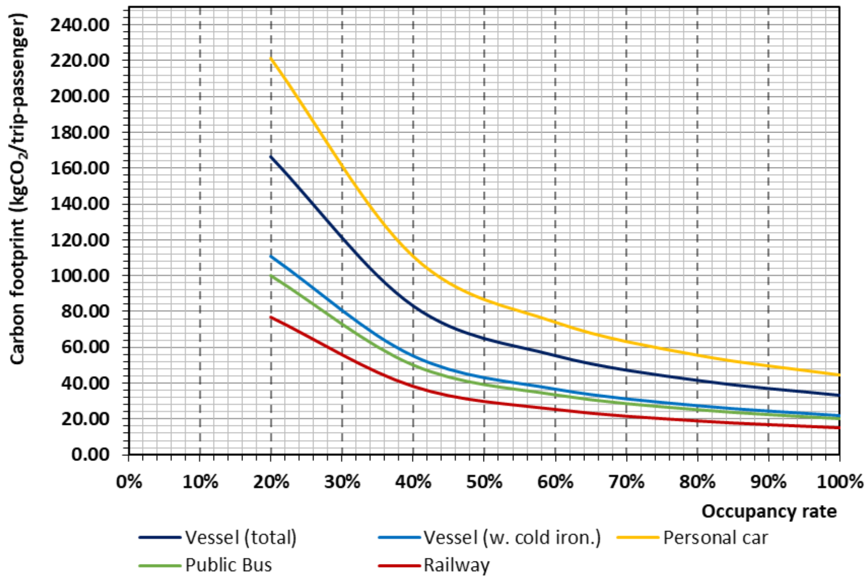
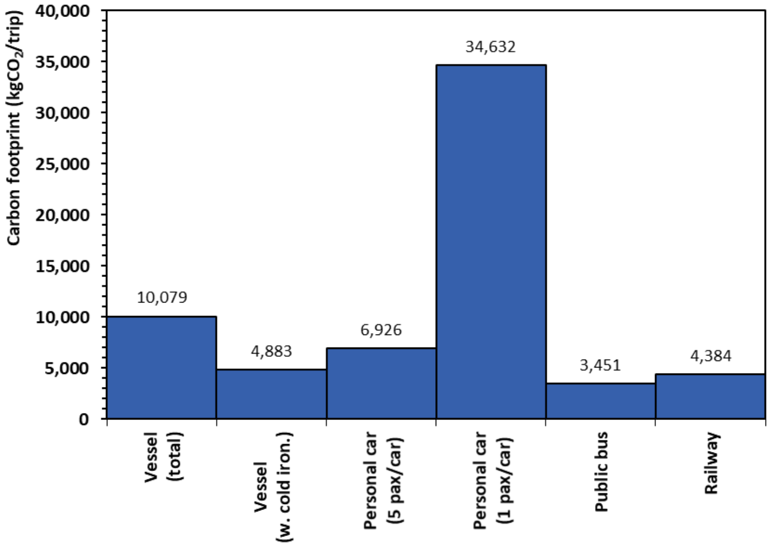



Figure 54. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route Dubrovnik – Bari

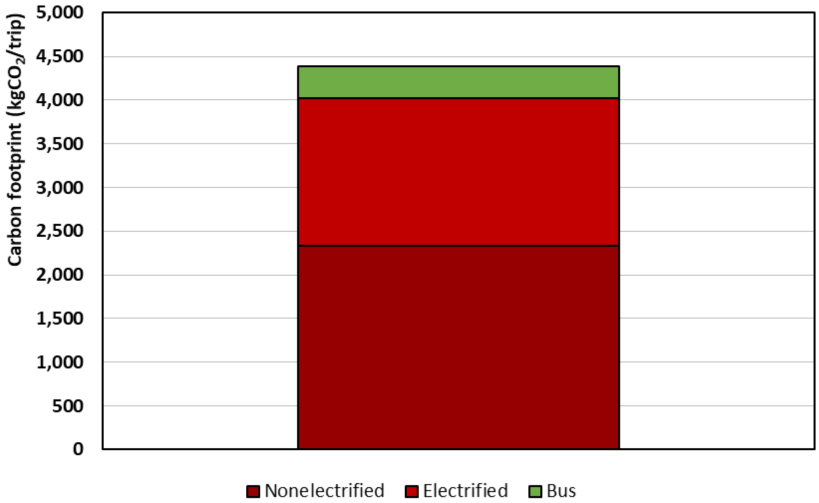
## 5.4. Case study 4 – Pesaro – Novalja – Mali Lošinj Results and Discussion

In this section, the carbon footprint calculation for the route Pesaro – Novalja – Mali Lošinj – Pesaro is considered. This route was divided into three interconnected segments. The first segment is Pesaro – Novalja, the second segment is Novalja – Mali Lošinj, and the last is Mali Lošinj – Pesaro. Further analysis of the calculated results will be based on these segments.

According to the calculated carbon footprint for the first segment of the route presented in Figure 55a, for the reference capacity of 400 passengers, the calculated carbon footprint for the maritime transportation mode is 10,079 $kgCO_2$ per trip. In case that the vessel is on cold ironing during port stays, and carbon footprint is considerably lower (4,883 $kgCO_2$ per trip). If technical conditions in ports and vessel allow cold ironing to be fully implemented, the total carbon footprint will be in this case lower for approximately 51%. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 34,632 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 6,926 $kgCO_2$ per trip. However, if the public buses employed on this route segment are fully occupied, a significantly lower carbon footprint of 3,451 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 4,384 $kgCO_2$ per trip. This value obtained for railway transportation mode considers usage of two trains required to transport reference capacity of 400 passengers and it is achieved by traveling on nonelectrified, electrified and public buses as the final destination cannot be reached by railway as presented in Figure 55b.




(a)




(b)

Figure 55. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 400 passengers (Route segment Pesaro – Novalja); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Pesaro – Novalja)

According to the results presented in Figure 56, the maritime transportation mode choice (without considering cold ironing) was identified as the one with the highest carbon footprint value in accordance with the reference capacity. In case that cold ironing is taken into consideration the maritime transportation mode is more favourable than the personal car transportation mode. On the other hand, the lowest calculated carbon footprint value is associated with public bus transport. Moreover, railway transportation mode choice is slightly more acceptable than maritime transport with cold ironing included. Since the curves are relatively close to each other, the difference in relative occupancy rates is the key determinant of the appropriateness of choosing a particular mode of travel in terms of the carbon footprint impact.

However, if the public bus transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 76% (average 37 passengers per public bus), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 11 $kgCO_2$/trip-passenger.

According to Figure 56, if the worst calculated carbon footprint value for public bus mode choice (a relative occupancy of 20%, generating 39.13 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the railway transportation mode being occupied 28% (total of 112 passengers), maritime transportation mode (with cold ironing) being occupied 34% (136 passengers), personal car being occupied 43% (2 passengers per personal car) and maritime transportation mode (without cold ironing) occupied 63% (252 passengers). Above those relative occupancy rates, the aforementioned transportation modes will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the maritime transportation mode (without cold ironing) is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (400 passengers), it can be concluded that the personal car transportation mode needs to be occupied less than 70% (4 passengers per personal car) to be less favourable. Moreover, the maritime transportation mode choice (with cold ironing) needs to be occupied less than 46% (184 passengers), and the railway transportation mode choice less than 42% (total of 168 passengers) to be less favourable than the railway transportation mode.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

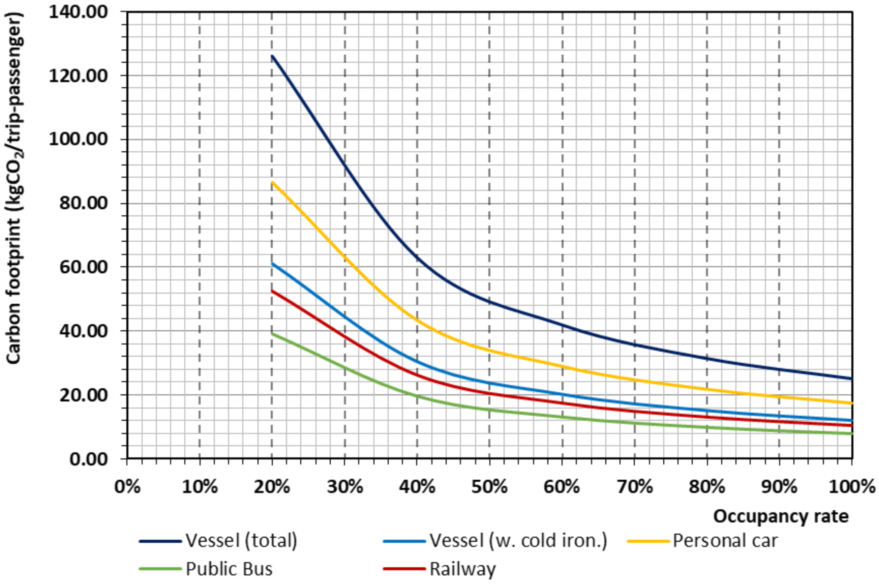



Figure 56. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Pesaro – Novalja

According to the calculated carbon footprint for the second route segment presented in Figure 57, for the reference capacity of 400 passengers, the calculated carbon footprint for the maritime transportation mode is 1,702 $kgCO_2$ per trip which includes port stay carbon footprint. In case that the vessel is on cold ironing during the port stay, the carbon footprint is lower (1,223 $kgCO_2$ per trip). If technical conditions in ports and vessel allows cold ironing to be fully implemented, the total carbon footprint will be lower for approximately 28%. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 11,292 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 2,258 $kgCO_2$ per trip. This value is considerably higher than the one of the maritime transportation modes. However, if the public buses employed on this route segment are fully occupied, in regard to reference capacity (400 passengers), a significantly lower carbon footprint of 1,125 $kgCO_2$ per trip is generated. Since both destinations cannot be reached by the railway transportation mode and existing route segment distances are significantly longer than the road route segment, the railway transportation mode in this case is not preferable from practical standpoint.

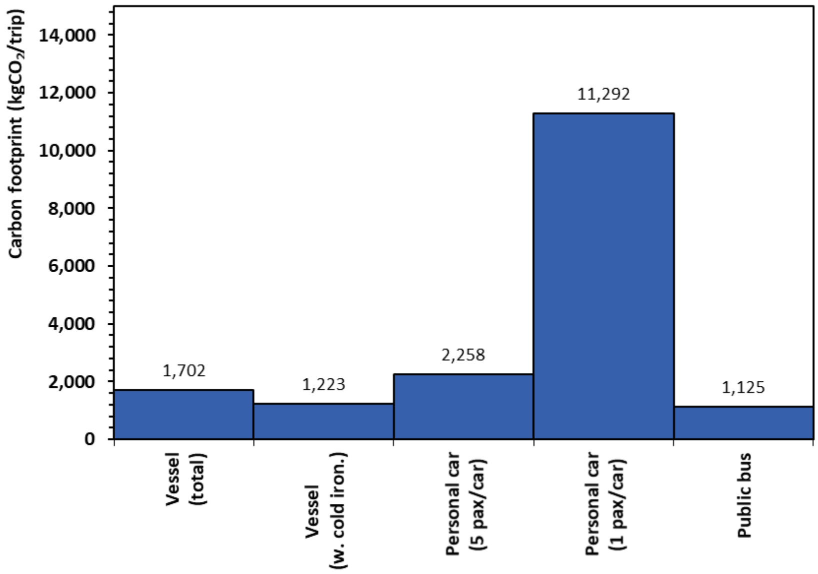



Figure 57. Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 400 passengers (Route segment Novalja – Mali Lošinj)

According to the results presented in Figure 58, the personal car transportation mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with public bus transport. Since both origin and destination are located on the islands, no direct railway connection is available. Furthermore, due to the above reason, the railway transportation mode is not considered as it is not a reasonable travel mode choice due to the lack of railway infrastructure and unacceptable time-distance proportion. Moreover, the maritime transportation mode curve shows intermediate values compared to the personal car and public bus mode choices.

However, if the public bus transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 82% (40 passengers per public bus), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is 3.1 kg$CO_2$/trip-passenger).

According to Figure 58, if the worst calculated carbon footprint value for public bus mode choice (a relative occupancy of 20%, generating 12.76 kg$CO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents equivalent to the maritime transportation mode (cold ironing included) being occupied 26% (104 passengers), maritime transportation mode (cold ironing excluded) being occupied 34% (136 passengers) and personal car being occupied 43% (2 passengers per personal car). Above those relative occupancy rates, maritime transportation mode and personal car will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car mode choice is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (400 passengers), it can be concluded that the maritime transportation mode (cold ironing excluded) needs to be occupied less than 76% (304 passengers) to be less favourable and 55% (220 passengers) if maritime transportation mode (cold ironing included) is taken into account. Moreover, the public bus mode choice needs to be occupied less than 43% (21 passengers per public bus) to be less favourable than the personal car mode choice.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

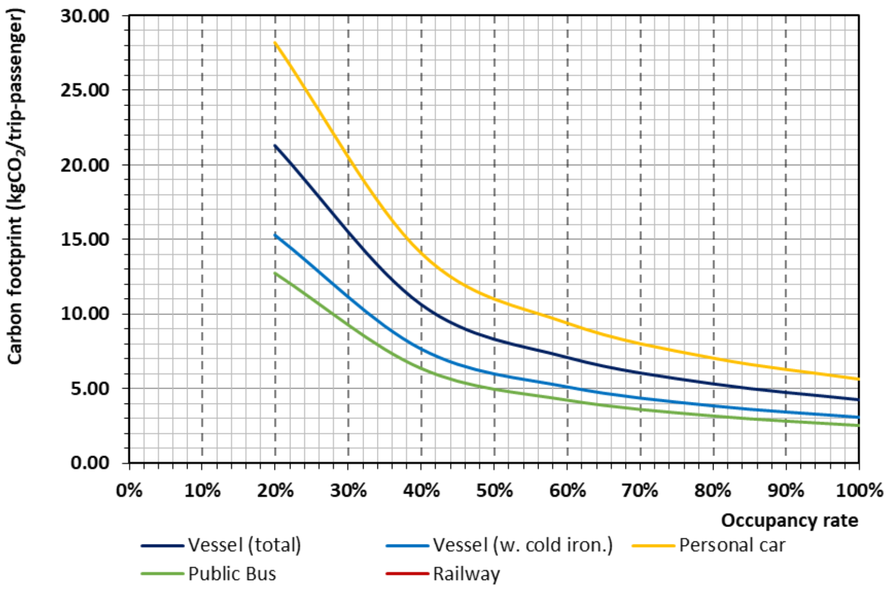
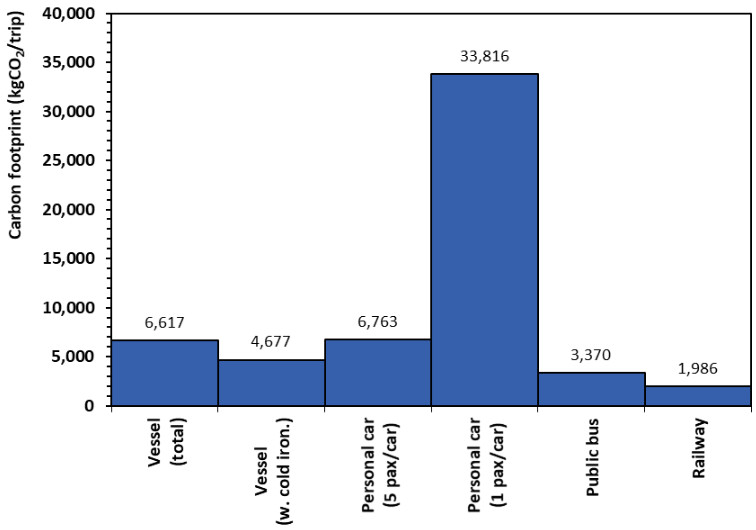
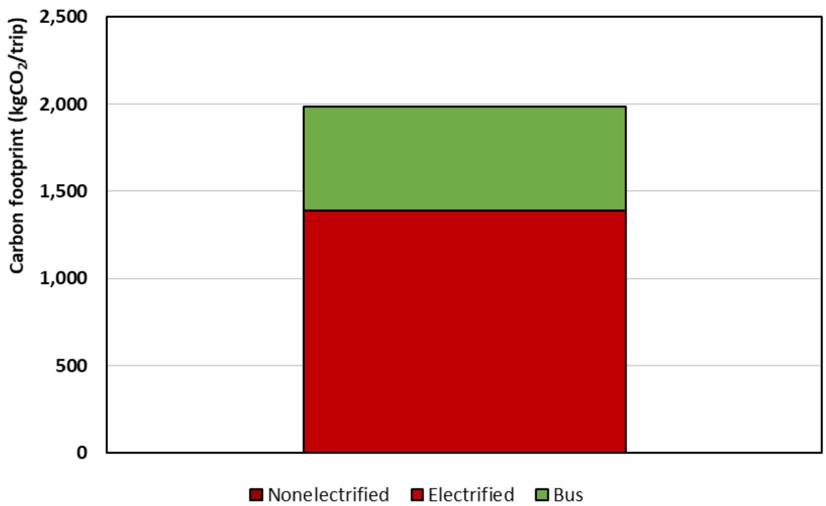



Figure 58. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Novalja – Mali Lošinj

According to the calculated carbon footprint for the last segment of the route, presented in Figure 59a, and for the reference capacity of 400 passengers, the calculated carbon footprint for the maritime transportation mode is 6,617 $kgCO_2$ per trip which includes port stay carbon footprint. In case that the vessel is on cold ironing during port stays, carbon footprint is considerably lower (4,677 $kgCO_2$ per trip). If technical conditions in ports and vessel allows cold ironing to be fully implemented, the total carbon footprint will be in this case lower for approximately 29%. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 33,816 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 6,763 $kgCO_2$ per trip. However, if the public buses employed on this route segment are fully occupied, in regards to the reference capacity, a significantly lower carbon footprint of 3,370 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 1,986 $kgCO_2$ per trip. However, given the above remark, a small part on the route segment needs to be covered by road (public bus is taken as an example) because the destination is not reachable by the railway transportation mode choice as presented in Figure 59b.




(a)



(**b**)

Figure 59. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment Mali Lošinj – Pesaro); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Mali Lošinj – Pesaro)

According to the results presented in Figure 60 the personal car transportation mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. The calculated Carbon footprint for personal car and maritime transportation mode choice when cold ironing is not considered are identical. On the other hand, the lowest calculated carbon footprint value is associated with railway transportation mode choice. Moreover, public bus mode choice is more acceptable than maritime transport when cold ironing is considered. Since the curves are relatively close to each other, the difference in relative occupancy rates is the key determinant of the appropriateness of choosing a particular mode of travel in terms of the carbon footprint impact.

However, if the railway transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 63% (total of 252 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 7 kg$CO_2$/trip-passenger).

According to the Figure 60, if the worst calculated carbon footprint value for railway transportation mode choice (a relative occupancy of 20%, generating 23.76 kg$CO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the public bus being occupied 34% (17 passengers per public bus), the maritime transportation mode with cold ironing included being occupied 48% (192 passengers), or the personal car being occupied 70% (4 passengers per personal car). Above those relative occupancy rates, public bus, maritime transportation mode (cold ironing included) and personal car mode choice will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car transportation mode choice is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (5 passengers per car), it can be concluded that the maritime transportation mode (cold ironing included) needs to be occupied less than 69% (276 passengers) to be less favourable. Moreover, the public bus mode choice needs to be occupied less than 43% (21 passenger per public bus), and the railway transportation mode choice less than 31% (total of 124 passengers) to be less favourable than the railway transportation mode.

The presented approach can be used in this context for further analysis and/or discussion in relation to the different setups or requirements.

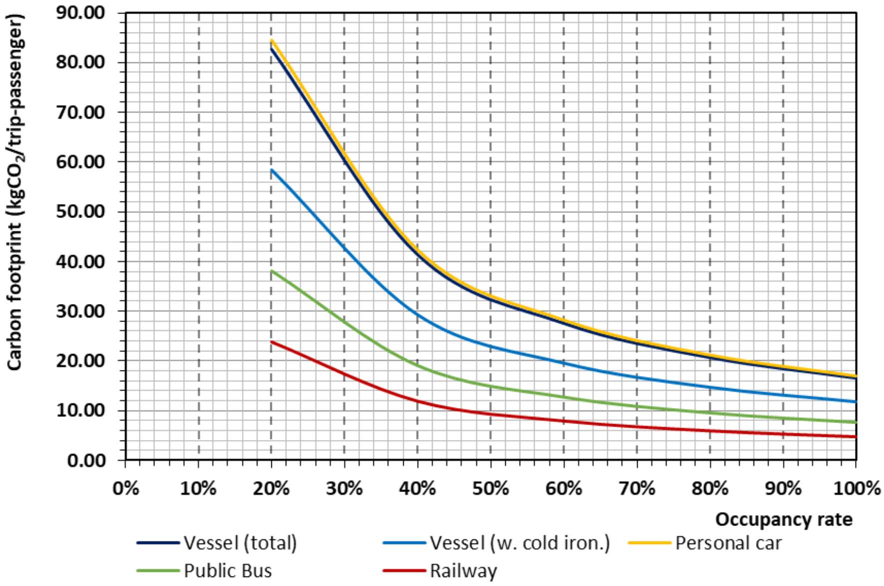
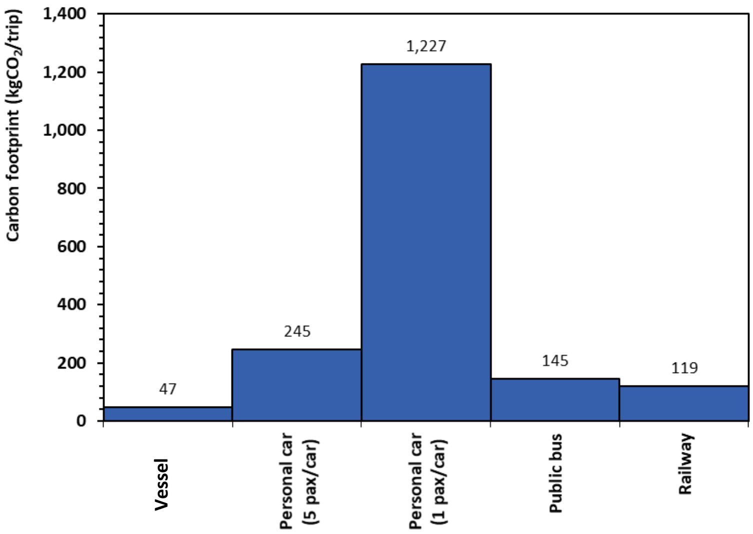



Figure 60. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Mali Lošinj – Pesaro

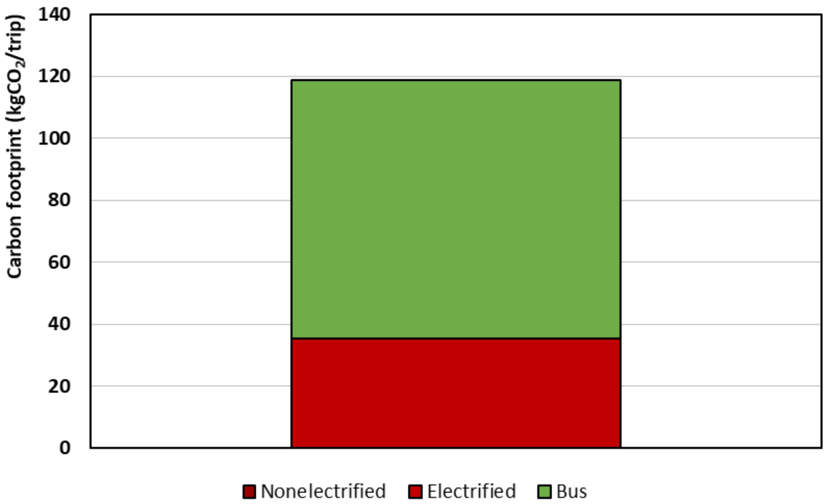
## 5.5. Case study 5 – Lignano – Grado – Trieste – Mali Lošinj Results and Discussion

In this section, the carbon footprint calculation for the route Lignano – Grado – Trieste – Mali Lošinj is considered. This route is divided in three interconnected segments. The first segment is Lignano – Grado, the second segment is Grado – Trieste and the last is Trieste – Mali Lošinj. Further analysis of the calculated results will be based on these segments.

According to the calculated carbon footprint for the first segment of the route presented in Figure 61a, and for the reference capacity of 150 passengers, the calculated carbon footprint for the maritime transportation mode is 47 $kgCO_2$ per trip which excludes port stay carbon footprint. In this particular case due to vessel size and operational pattern, port stays emission is usually not generated. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 1,227 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 245 $kgCO_2$ per trip. However, if the public buses employed on this route segment are fully occupied in regards to reference capacity (150 passengers), a significantly lower carbon footprint of 145 kg$CO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 119 kg$CO_2$ per trip. This value considers one train required to transport reference capacity of 150 passengers and is achieved by traveling both by electrified railway sections and public buses as presented in Figure 61b.




(a)




(b)

Figure 61. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment

Lignano – Grado); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Lignano – Grado)

According to the results presented in Figure 62, the personal car mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with maritime transportation mode. Moreover, results obtained for railway and public bus are slightly higher than maritime transport. Since those curves are relatively close to each other, there are no significantly difference in carbon footprint regarding relative occupancy rates.

However, if the maritime transportation mode is taken as a reference, as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 50% (total of 75 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 0.57 kg$CO_2$/trip-passenger).

According to Figure 62, if the worst calculated carbon footprint value for maritime transportation mode (a relative occupancy of 20%, generating 1.57 kg$CO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent to the railway transportation mode choice and public bus being occupied approximately 36% and 45% respectively (total of 75 passengers for train, or 22 passengers per public bus). Above those relative occupancy rates, later mentioned transportation modes will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car mode choice is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (5 passengers per personal car), it can be concluded that the public bus needs to be occupied less than 45% (22 passengers per public bus), railway transportation mode to be less than 36% to be less favourable.

The presented approach can be used in this context for further analysis and/or discussion concerning the different setups or requirements.

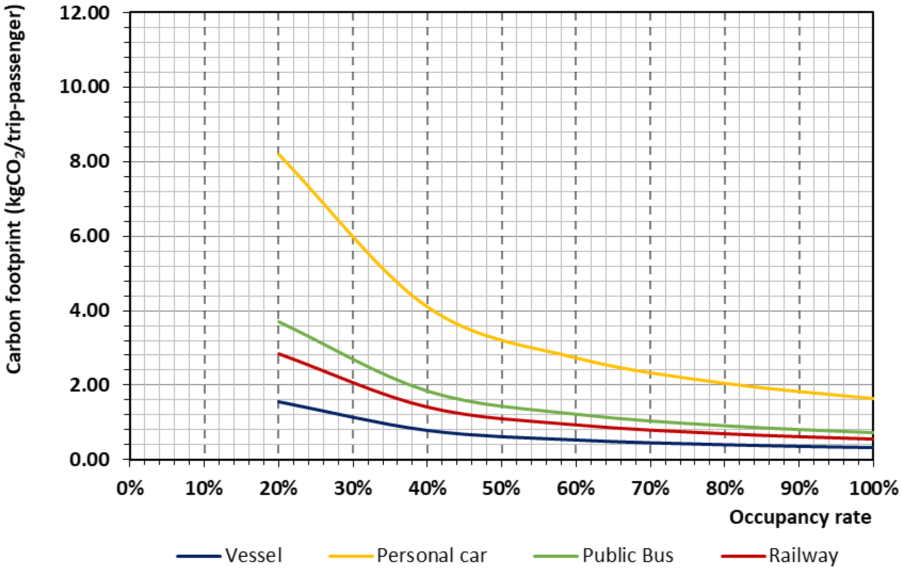
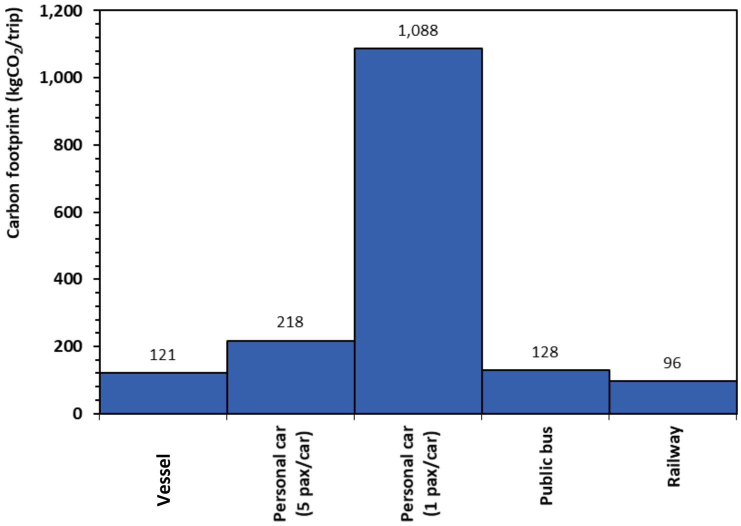
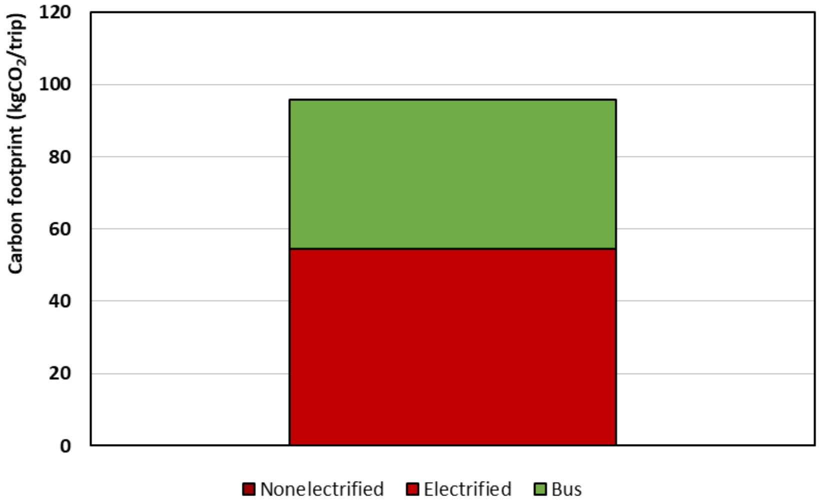



Figure 62. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Lignano – Grado

According to the calculated carbon footprint for the second segment of the route presented in Figure 63a, and for the reference capacity of 150 passengers, the calculated carbon footprint for the maritime transportation mode is 121 $kgCO_2$ per trip. In this particular case also, due to vessel size and operational pattern, port stays emission is usually not generated. If the same number of passengers is transported by personal cars, the calculated carbon footprint is considerably higher: 1,088 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers), the total calculated carbon footprint is 218 $kgCO_2$ per trip. However, if the public buses employed on this route segment are fully occupied in regards to reference capacity (150 passengers), a significantly lower carbon footprint of 128 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 96 $kgCO_2$ per trip. This value considers one train required to transport reference capacity of 150 passengers and is achieved by traveling both by electrified railway sections and public buses as presented in Figure 63b.




(**a**)




(**b**)

Figure 63. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 330 passengers (Route segment Grado – Trieste); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Grado – Trieste)

According to the results presented in Figure 64, the personal car mode choice was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with railway transportation mode choice. Moreover, results obtained for public bus and maritime transportation mode choice are lower than personal car mode choice. Since those curves are relatively close to each other (especially for public bus and maritime transportation mode choice), there are not significantly different in carbon footprint regarding relative occupancy rates.

However, if the railway transportation mode choice is taken as a reference, as the most favourable transportation mode, the conclusion can be drawn that above a relative occupancy of 68% (total of 142 passengers), no other transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 0.65 $kgCO_2$/trip-passenger).

According to Figure 64, if the worst calculated carbon footprint value for railway transportation mode (a relative occupancy of 20%, generating 2.29 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents the equivalent that the maritime transportation mode choice, public bus and personal car being occupied approximately 37%, 32%, and 64% respectively (56 passengers, 16 passengers per public bus, and 3 passengers per personal car). Above those relative occupancy rates, the aforementioned transportation modes will offer more acceptable carbon footprint values.

On the other hand, under the assumption that the personal car mode choice is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (5 passengers per personal car), it can be concluded that the public bus has to be occupied less than 45% (22 passengers per public bus), maritime transportation mode less than 56% (84 passengers), and railway transportation mode less than 33% (total of 69 passengers) to be less favourable.

The presented approach can be used in this context for further analysis and/or discussion concerning the different setups or requirements.

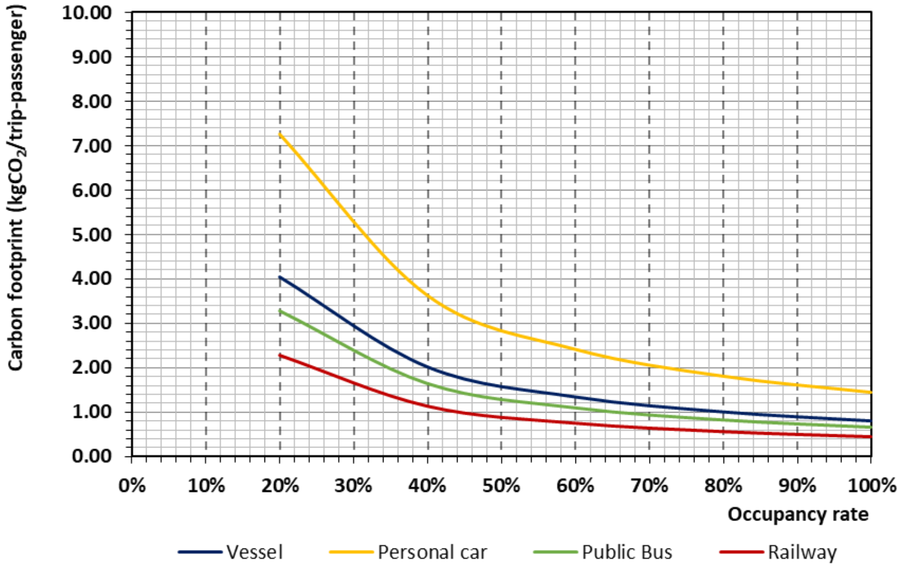
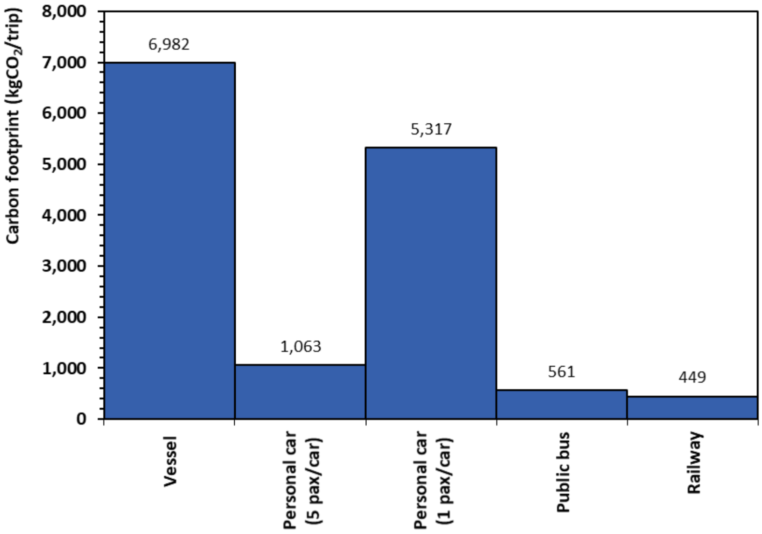
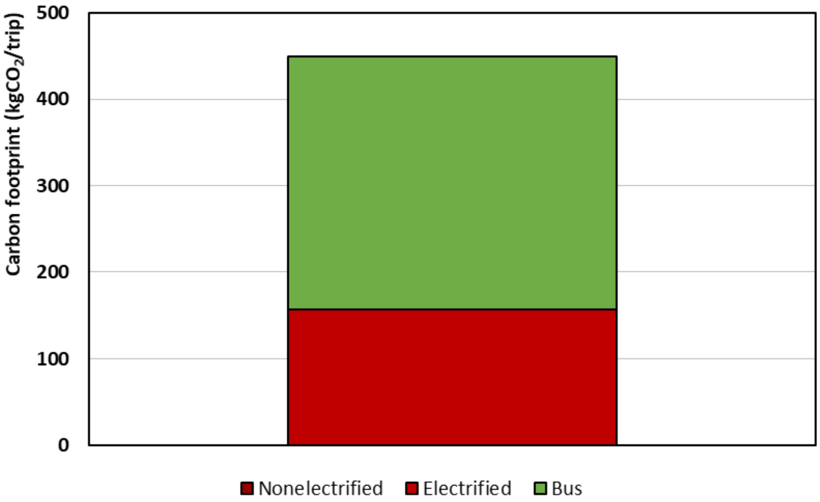



Figure 64. Calculated carbon footprint per trip-pax ($kgCO_2$) for single trip based on occupancy rate for the route segment Grado – Trieste

According to the calculated carbon footprint presented in Figure 65a, for the third route segment and for the different reference capacity of 210 passengers (different line operator and different reference vessel), the calculated carbon footprint for the maritime transportation mode is 5082 $kgCO_2$ per trip. In this particular case also, due to vessel size and operational pattern, port stays emission is usually not generated and therefore not considered. If the same number of passengers is transported by personal cars, the calculated carbon footprint is higher: 5,317 $kgCO_2$ per trip. However, the road transportation mode is influenced mainly by the occupancy rate, i.e., in case that the reference passenger capacity is transported at full personal car occupancy (5 passengers per car), the total calculated carbon footprint is 1,063 $kgCO_2$ per trip. However, if the public buses employed on this route are fully occupied in regards to reference capacity (210 passengers), a significant lower carbon footprint of 561 $kgCO_2$ per trip is generated. Since the reference capacity was used, the carbon footprint for the railway transportation mode is 449 $kgCO_2$ per trip. This value considers usage of one train required to transport reference capacity and is achieved by traveling both on electrified railway sections and public buses as well as presented in Figure 65b.




(a)




(b)

Figure 65. (a) Comparison of the total carbon footprint per trip with respect to the different transportation mode choices and the reference capacity of 210 passengers (Route segment Trieste – Mali Lošinj); (b) Carbon footprint for railway transportation mode based on railway section features (Route segment Trieste – Mali Lošinj)

According to the results presented in Figure 66, the maritime transportation mode choice and personal car occupied by driver only was identified as the one with the highest carbon footprint value in accordance with the reference capacity. On the other hand, the lowest calculated carbon footprint value is associated with railway transport. Moreover, public bus transport mode shows similar carbon footprint value as railway transportation mode choice. Those two mentioned modes are more favourable than personal car mode choice.

However, if the railway transportation mode is taken as a reference (public bus in this case as well), as the most favourable transport mode, the conclusion can be drawn that above a relative occupancy of 46% (total 97 passenger or 23 passengers per public bus), neither maritime transportation mode or personal cars transportation mode choice can deliver a lower carbon footprint per trip-passenger. In this case, the calculated carbon footprint is approximately 5.06 $kgCO_2$/trip-passenger).

According to Figure 66, if the worst calculated carbon footprint value for railway mode choice (a relative occupancy of 20%, generating 10.69 $kgCO_2$/trip-passenger) is used as a reference, it can be concluded that this value presents equivalent to the personal car being occupied 44% (2 passengers per personal car). Above those relative occupancy rates, personal car transportation modes will offer more acceptable carbon footprint values. In this case maritime transportation mode will offer the highest carbon footprint.

On the other hand, under the assumption that, assuming full capacity for all modes, the maritime transportation mode is considered as the least favourable transportation mode, if the relative occupancy rate is 100% (210 passengers), it can be concluded that the railway transportation mode needs to be occupied less than 20% (less than 40 passengers per train or 1 passenger per personal car) to be less favourable.

The presented approach can be used in this context for further analysis and/or discussion concerning the different setups or requirements.

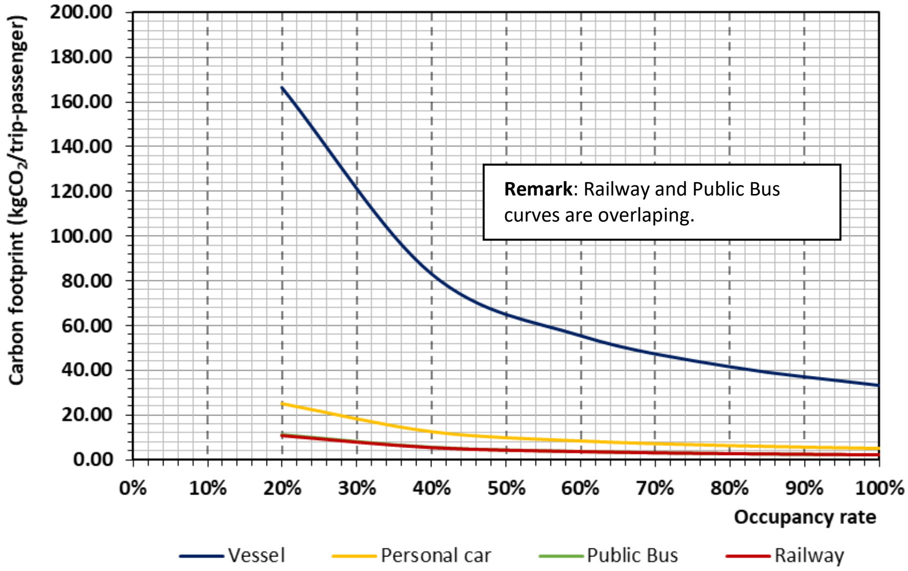
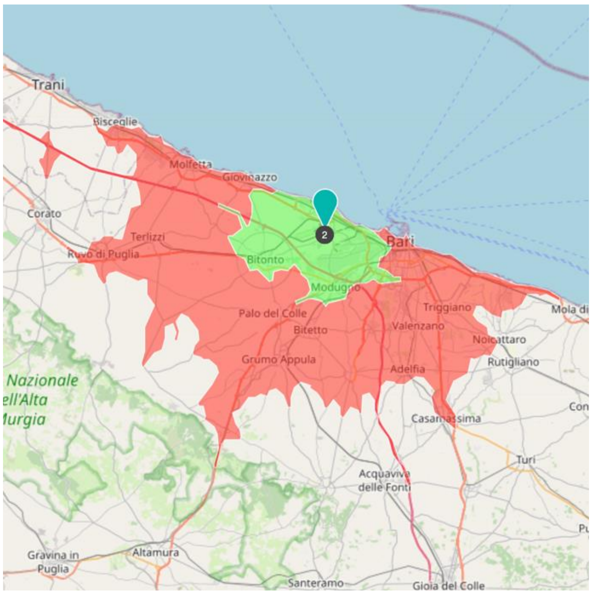



Figure 66. Calculated carbon footprint values with respect to the relative occupancy rates for the route segment Trieste – Mali Lošinj

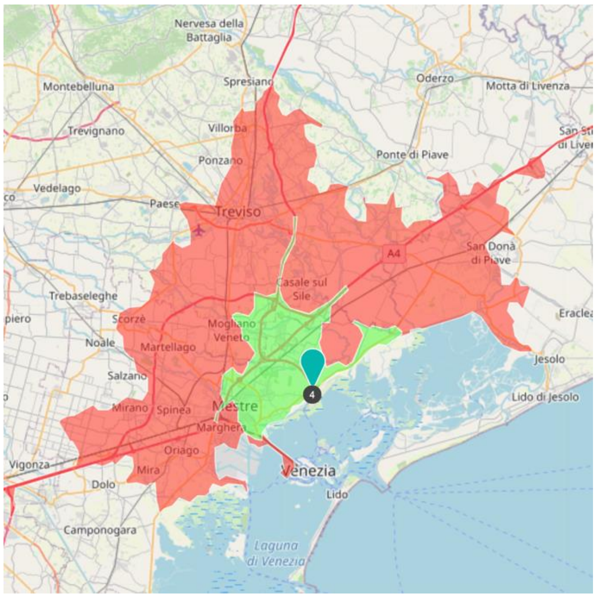
# 6. Flight emissions from travel between main Italy-Croatia programme area airports

In this section of the report, an estimation of the emissions of air trips calculated between the main international airports of the programme area (Bari, Dubrovnik, Split, Trieste, Venice) plus the airport of Zagreb is provided. All these airports can be considered relevant by virtue of their location and/or their area of attraction near tourist destinations. On basis of other analysis in the MIMOSA project (see Output 3.1), about 2% of Italian travelers and about 6% of Croatian travelers use the airplane for their trips. For Croatian tourists destinations are mainly outside the programme area (Croatians mainly travel to Rome, Naples, Turin, Florence, Milan), and the same is for the origin of Italians travelers to Croatia. Therefore, as possible extension of the emissions calculation between selected airports, one might consider the possibility that airports in the programme area on both sides might be intermediate steps for further travels in the cross-border Country. However, it is visible that the carbon footprint of air travel is of such a magnitude and there is no need for further study in this regard. The emissions of even the shortest journeys are such that there is no doubt that air travel has a greater impact than other means of transport, except in very specific cases.

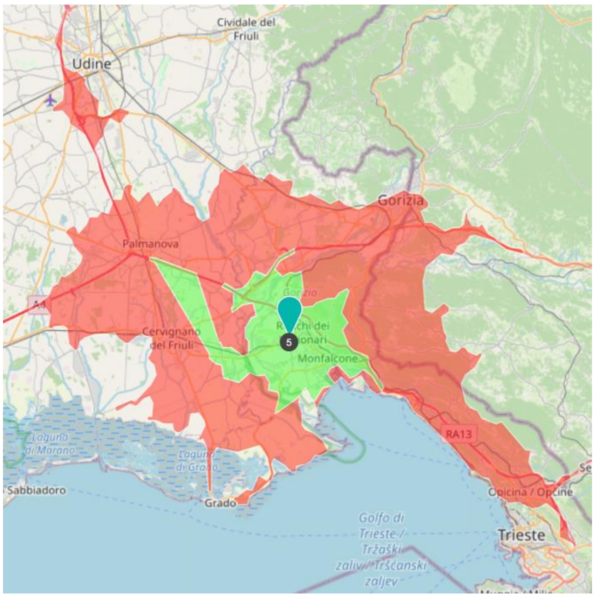
An estimate of the attraction area of the airports is obtained by measuring the isochrones corresponding to a driving distance of 15 and 30 minutes. For this measurement analysis, the Openrouteservice portal is used [46]. Furthermore, it is important to state that the “reach factor” is an index calculated by Openrouteservice as a proportion of the isochron generated by the system according to the average speed of the chosen mode. Therefore, it is not an indicator of accessibility in strict sense, rather a measure of street density around the attraction point, since it measures how much the isochrones overlaps an ideal circle representing the area that would be reachable if cars could travel at medium speed in all possible directions without limitations. The results are shown in the following figures.



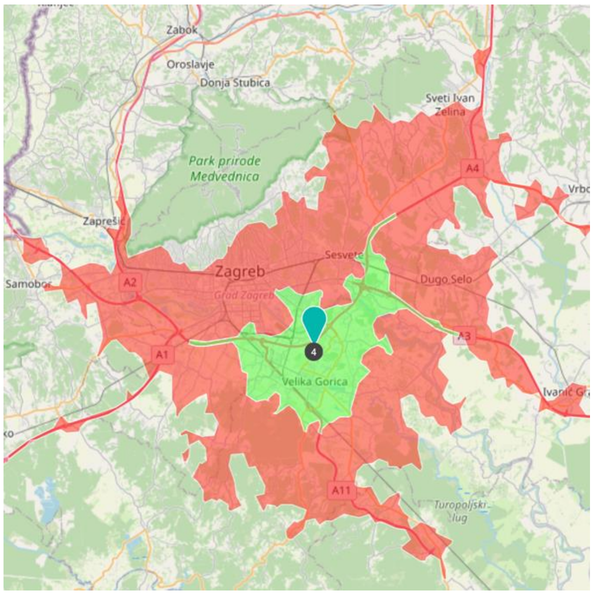

Bari Karol Wojtyla Int. Airport – BRI



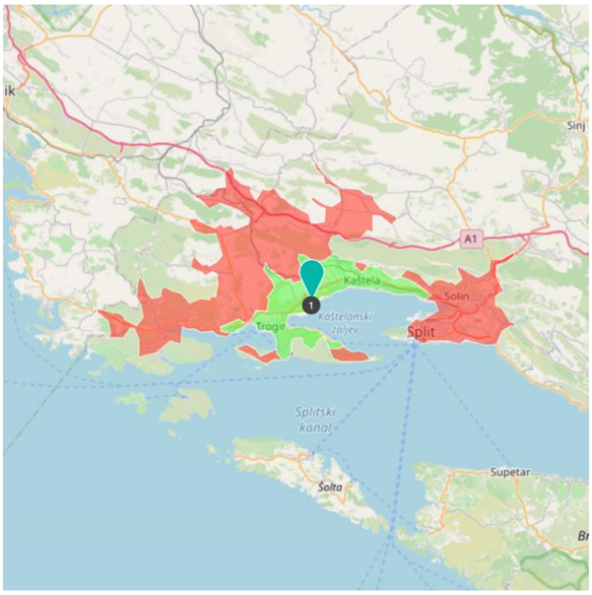

Venice Marco Polo Int. Airport – VCE



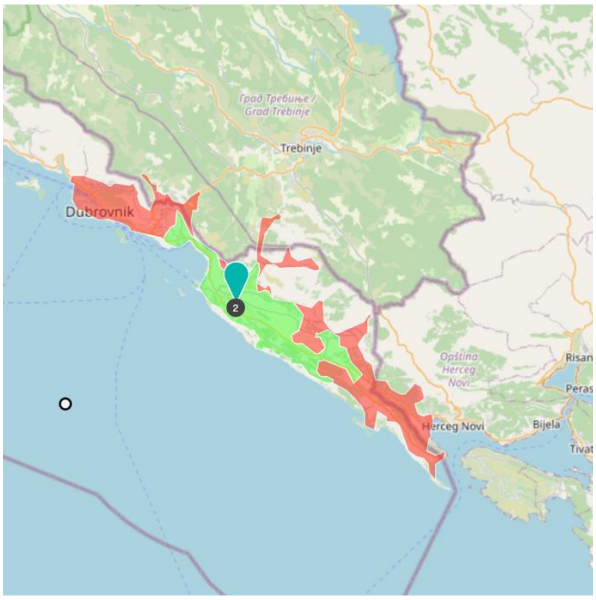

Trieste Ronchi dei Legionari Int. Airport - TRS




Zagreb Franjo Tuđman Int. Airport - ZAG




Split Zračna luka Int. Airport – SPU




Dubrovnik Zračna luka Int. Airport – DU

Figure 67. The isochrones of the attraction area calculated for 15’ and 30’ minutes by car/bus for the selected airports

For the emission calculation, the tool which is available by European Environment Agency (EEA): “1.A.3.a Aviation 1 Master emissions calculator 2019” is used in this analysis [47]. This tool includes in the calculation the route distance and flight times depending on the type of aircraft, and the average ground operation time calculated based on a European average (therefore, it is not an airport-specific value). Furthermore, it requires distances to be entered in nautical miles. For the calculation of the routes and related distances in nautical miles several tests were made with different websites and georeferencing programs. At the end, the online air calculator is used for the calculation.

Furthermore, four aircrafts are used for the calculation: Airbus 320-200, and Boeing B737-800. These aircrafts are the most widely used with best ratio of emissions to the number of passengers carried on short-haul routes. They are within the fleets of the Ryanair and Croatia Airlines. Also, the one using the Airbus 319-100 has been included in the calculation although it is the least CO2 efficient among the aircrafts compared. The emissions of British Aerospace Dash 8-Q400 by the Croatian Airlines is also considered, but it was not included in the European Environment Agency's database. Therefore, the data for the British Aerospace ATP turboprop, very similar to the Dash8-Q400 are analysed. The results are shown that they have significantly lower absolute emissions and emissions per passenger/Km comparable to the A320-200 and B737-800.

The considered routes in this document have been selected because they represent important shares of cross-border trips, and at the same time, can be carried out with alternative means and multimodal solutions.

In fact, the comparison with most of the other routes considered in this document is not possible, given for airplanes emission. Only interconnection between international airports in the programme area can be measured. Of course, it could be calculated the emissions for identical routes by integrating the calculation of the CO2 emitted by flights with the connections to and from airports, but this would be redundant because it is clear from the analysis that air emissions are among the most unfavourable, except under the very particular conditions of a situation such as Bar-Dubrovnik (for which the comparison is provided). In the mentioned route, a very large land distance is matched by a very short air journey. In other situations, it is visible in the following analysis that air transportation is not in itself for the alternative improving of overall emissions.

The starting point for the calculation of air emissions was obtained by using the already mentioned EEA tool. Furthermore, the emissions for trip per passenger can be calculated. For the different aircrafts, the capacities (number of seats) are indicated by Croatian Airlines and Ryan Air for Airbus and Boeing from the manufacturer's data sheets. Results are shown in the following tables.

Table 31. Air travel emissions (Kg per trip and Kg per trip per passenger) of four different aircraft between international airports of the Italy-Croatia programme area, with additionally Zagreb International airport

| | | | | **Kg of CO2 per trip** | | | |
|---|---|---|---|---|---|---|---|
| | | **NM** | **KM** | **Airbus A320-200** | **Airbus A 319 - 100** | **British Aer. ATP*** | **Boeing B737-800** |
| Venice | Dubrovnik | 311 | 576 | 8,758.3 | 8,166.6 | 3,464.5 | 9,338.1 |
| Venice | Split | 237 | 439 | 7,521.9 | 6,979.6 | 2,855.8 | 8,027.8 |
| Trieste | Dubrovnik | 289 | 535 | 8,398.3 | 7,821.8 | 3,287.1 | 8,954.2 |
| Trieste | Split | 210 | 389 | 7,027.0 | 6,499.8 | 2,613.0 | 7,517.1 |
| Bari | Dubrovnik | 145 | 269 | 5,863.1 | 5,364.6 | 2,095.9 | 6,257.9 |
| Bari | Split | 168 | 311 | 6,273.2 | 5,765.0 | 2,274.6 | 6,705.4 |
| Venice | Zagreb | 180 | 333 | 6,487.1 | 5,974.0 | 2,367.8 | 6,938.9 |
| Trieste | Zagreb | 125 | 232 | 5,506.5 | 6,890.7 | 1,940.6 | 5,868.8 |
| Bari | Zagreb | 320 | 593 | 8,905.6 | 8,307.7 | 3,537.1 | 9,495.2 |

| | | | | **Kg of CO2 per trip per passenger* at full load** | | | |
|---|---|---|---|---|---|---|---|
| | | **NM** | **KM** | **Airbus A320-200** | **Airbus A 319 - 100** | **British Aer. ATP*** | **Boeing B737-800** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Venice | Dubrovnik | 311 | 576 | 50.3 | 56.7 | 52.5 | 50.2 |
| Venice | Split | 237 | 439 | 43.2 | 48.5 | 43.3 | 43.2 |
| Trieste | Dubrovnik | 289 | 535 | 48.3 | 54.3 | 49.8 | 48.1 |
| Trieste | Split | 210 | 389 | 40.4 | 45.1 | 39.6 | 40.4 |
| Bari | Dubrovnik | 145 | 269 | 33.7 | 37.3 | 31.8 | 33.6 |
| Bari | Split | 168 | 311 | 36.1 | 40.0 | 34.5 | 36.1 |
| Venice | Zagreb | 180 | 333 | 37.3 | 41.5 | 35.9 | 37.3 |
| Trieste | Zagreb | 125 | 232 | 31.6 | 47.9 | 29.4 | 31.6 |
| Bari | Zagreb | 320 | 593 | 51.2 | 57.9 | 53.6 | 51.0 |
| **** Number of passengers' seats*** | | | | ***174*** | ***144*** | ***66*** | ***186*** |

| | | | | Kg of CO2 per trip per passenger at full load | | |
|---|---|---|---|---|---|---|
| | | **Km land travel** | **Km flight** | Airplane (Avg) | Car | Bus |
| Venice | Dubrovnik | 833 | 576 | 52.4 | 22.61 | 6.27 |
| Venice | Split | 642 | 439 | 44.5 | 17.42 | 4.83 |
| Trieste | Dubrovnik | 676 | 535 | 50.1 | 18.35 | 5.09 |
| Trieste | Split | 485 | 389 | 41.4 | 13.16 | 3.65 |
| Bari | Dubrovnik | 1,636 | 269 | 34.1 | 44.40 | 12.31 |
| Bari | Split | 1,445 | 311 | 36.7 | 39.22 | 10.87 |
| Venice | Zagreb | 373 | 333 | 38.0 | 10.12 | 2.81 |
| Trieste | Zagreb | 264 | 232 | 35.1 | 7.16 | 1.99 |
| Bari | Zagreb | 1,174 | 593 | 53.4 | 31.86 | 8.83 |

Results show that the emissions per passenger per trip of the A320 and B737 are extremely similar, while in terms of absolute emissions per trip the least polluting aircraft is the BA ATP. The only cases in which the air travel has lower emissions per trip per passenger than the car are the Bari-Dubrovnik and Bari-Split routes (highlighted in yellow, data in red where air emissions per pax per trip are lower than car's ones). These two routes are obviously the most favourable situations for the airplane, since they compare a very short air trip with a very long car trip. For this route, Figure 68 shows that for the Bari-Dubrovnik route, even with the occupancy rate 20%, the air trip has, on average, a lower carbon footprint per passenger than the car.

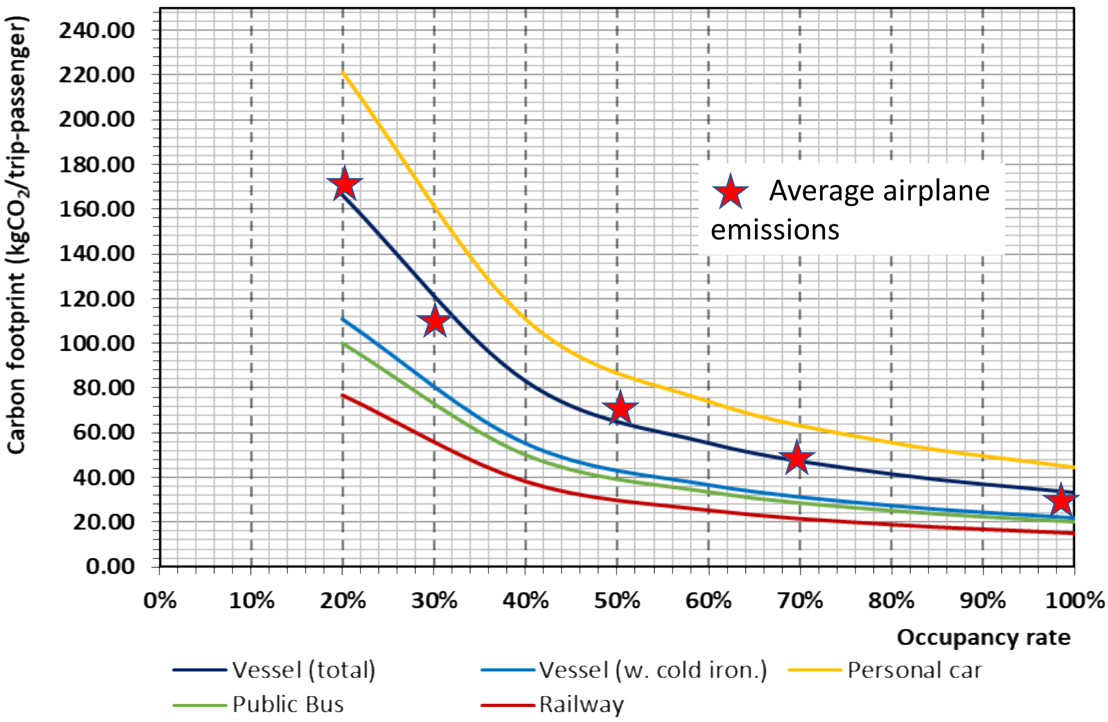



Figure 68. Calculated carbon footprint per trip-pax (kgCO2) for single trip based on occupancy rate for the route Dubrovnik – Bari (see fig. 54): comparison with average airplane emissions

However, it is reasonable to assume that for car transfers between Bari and Dubrovnik (as well as between Bari and Split) travellers prefer the ferry, which also gives them the possibility to take their car with them and avoid the long journey around the Adriatic.

In conclusion, this comparison has been provided for the sake of completeness, and it confirms what has already emerged in the scenario study (D.3.1.4.). As far as trips in the programme area are concerned, shifting passengers from cars to airplane is not an option to improve the carbon footprint. It might be for some very specific case, hardly in terms of general policy orientation, and however this would not be a priority in a logic of multimodal transport improvement. In fact, in all other routes taken into consideration the air travel has a higher carbon footprint than the car, independently from the occupancy rate.

# 7. Conclusions

This work presents an analysis to assess the carbon footprint of the passengers' transportation mode choices between Italy and Croatia. Transportation modes chosen for the carbon footprint comparison include maritime and two land modes (road and railways). For the road transportation mode, a comparison between personal cars and public buses is made. This analysis is based on the present transportation network available in three main regions that are part of the Italy – Croatia Adriatic region. In each of the mentioned regions, example routes had been chosen based on the presently available sea routes, the difference in the destination locations and the transport modes availability, history passenger flows, and vessel types. Therefore, the chosen routes are: Venice – Pula – Poreč, Lignano – Grado - Trieste – Mali Lošinj, Pesaro – Novalja – Mali Lošinj, Ancona – Zadar, and Dubrovnik – Bari.

The methodology used for calculating the carbon footprint for each of the chosen transportation modes is different due to the different technical characteristics and operation modes, different industry regulations, different industry standards, and data availability. The carbon footprint of the maritime transportation mode is based on presently available models for calculating emissions for specific vessels based on propulsion plant operational data. Moreover, the carbon footprint of the road transportation modes is based on industry available average emission factors for public cars and public buses. Carbon footprint for railway transportation modes is based on publicly available emission data for passenger-kilometer for electrified route sections, while for non-electrified route segments is calculated based on fuel consumption and average speed/distance. The carbon footprint for each selected route is calculated for the reference capacity, which is different for each route and is based on the vessel size operating on a particular route.

Generally, railway passenger transportation shows lowest carbon footprint at most of the passenger transportation routes. Even where public buses have to be used instead of trains due to railway infrastructure non-existence where final destinations cannot be reached by railway, the carbon footprint values still indicate lowest impact.

The analysis of the relatively short circular routes in the Northern Adriatic region, which consists of several midpoints as Lignano – Grado – Trieste shows that the maritime transportation mode has lower carbon footprint impact than using road transportation mode by public bus or personal car. However, following this route on next Trieste – Mali Lošinj section shows that maritime transportation mode is not preferable as in first route sections. In this later case, the occupancy rates for different transportation modes shows a higher carbon footprint overall efficiency. In this particular route using of HSC vessel craft on route sections shows a higher carbon footprint impact versus the carbon footprint achieved by motorboat impact. Furthermore, maritime transportation mode in some cases (Lignano – Grado) presents even lower carbon footprint impact than railway.

Other route in North Adriatic (Venice – Pula – Poreč) shows that railway and public busses present the lowest carbon footprint in regards to transport work performed. Maritime transport mode as well as usage of personal car shows the highest carbon footprint. Usage of ship cold ironing during port stay might bring some additional reduction in footprint levels and change preferability between personal car mode choice and maritime transportation mode. Since the occupancy rate vs transport work carbon footprint curves are spaced, large differences in occupancy rate between different transportation modes might change emission preferability decision. Based on previously discussed analysis usage of motorboat instead of HSC would also offer reduced carbon footprint rates.

Single lines between two destinations in the Middle and Southern Adriatic regions, which includes lines Ancona – Zadar and Dubrovnik – Bari, show higher preferability for maritime transportation but still below railway and public bus transportation. In this particular case carbon footprint reductions caused by avoiding emissions during port stay would significantly change preferability choice. This is especially observable in the route Ancona – Zadar where by avoiding emissions during port stay would offer lowest carbon footprint, even slightly lower than railway transportation mode. This might be a baseline for creating initiatives to implement the possibility of cold ironing for ferries on this route with the support of renewable energy. In these two cases, traveling by personal cars shows relative high carbon footprint impact. However, changes in occupancy rate and the number of passengers demands for particular transportation modes might shift preferability choice from a carbon footprint standpoint.

The circular route with midpoints in the Northern Adriatic region with destinations on the Croatian islands is represented by the Pesaro – Novalja – Mali Lošinj line. The analysis for this line shows that the railway transportation mode followed by road transportation mode by means of using public bus is the most preferable from a carbon footprint standpoint. In this particular route example, using the road transportation mode by utilizing personal cars shows a relatively high carbon footprint which is comparable to the maritime transportation mode. However, as in previous analysis, by implementing cold ironing, maritime transportation mode would greatly improve preferability in regards to personal cars under the assumption of same occupancy rate and capacities. In this case, differences in the occupancy rate and capacities might change the preferability of the transportation mode choice from the carbon footprint standpoint. However, implementing motorboat instead of HSC on this route would additionally increase preferability of maritime transportation mode choice in regards to the carbon footprint. As with the railway transportation mode, two destinations on the two Croatian islands (destinations Novalja and Mali Lošinj) cannot be reached, this mode was not considered on this route segment.

Additionally, the flight emissions between the main international airports of the programme area (Bari, Dubrovnik, Split, Trieste, Venice) with additionally airport of Zagreb are provided. The results of air travel emissions (Kg per trip and Kg per trip per passenger) for four different aircrafts have been compared with other transportation nodes. As far as trips in the programme area are concerned, shifting passengers from cars to the airplane is not an option to improve the carbon footprint. Nevertheless, it might be for some very specific case, hardly in terms of general policy orientation, and however this would not be a priority in a logic of multimodal transport improvement. By taking all air transportation routes in the programme area, the air travel has a higher carbon footprint than the car, independently from the occupancy rate.

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