Maritime Green Solution for Traffic Congestion

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ABSTRACT: Traffic congestion is a wide problem in many tourist destinations. Airports are usually distant from the city centers. Hence, road and rail traffic are widely used to connect airports and city centers. In this paper, we propose zero-emission solution for connection between airport and the center at the example of Croatian city Split. Since Split has become a popular tourist destination, the number of vehicles during summer season increases. As a measure to decrease air pollution, in this paper the marine traffic by electric vessels is proposed for the route Split – airport. Seven all-electrical vessels are presented with their technical characteristics. The idea is to have zero emission transfers by sea from the center of the Split to the airport. The criteria for minimum cruising speed is set to 13 knots, which ensures that one crossing takes 30 minutes and makes it competitive with other forms of transport.

1 INTRODUCTION

Split is a second largest city in Croatia that has become popular tourist destination. It is located on the south of Croatia in the region called Dalmatia. Next to Split in the north-west direction the town Solin is located. Next to Solin there is city of Kaštela. Kaštela is the name for the agglomeration that consists of seven small towns. Kaštela are located along the coastline. At the end of Kaštela the airport is located. The distance between the airport and Split is approximately 25 km. During summer season the traffic by state and local roads which lead from airport to Split gets congested.

Area around the Split harbor, which is located in Split center, contains bus terminal and train station. This situation combined with only one access road, leads to traffic congestion in the center of Split (Fig.1).

The consequence of increased traffic congestion is the additional air pollution caused by vehicle exhaust emission. The contribution to air pollution comes from the personal cars, taxi transfers (by cars and vans) and bus transportation (domestic and international). Once situated one portion of tourist explore the local towns. Trogir is popular town located approximately 31 km from Split in north-west direction. This transition leads through Solin and Kaštela which additionally contributes to air pollution.

To quantify mentioned statements statistics from the Airport "Split" and Croatian company for management, construction and maintenance of state roads "Hrvatske ceste" is used. Also, for number of tourist arrivals the statistic from Croatian bureau of statistics is used. The overall number shows that there is an increase in total number of airport passengers, number of vehicles and tourist arrivals. Figure 2 shows the graph of total airport passengers from January 2013 to March 2019. Figure 3 shows the average summer daily traffic (measured from July 1st

to August 31st) from 2014. to 2017. Figure 4 shows the total number or tourist arrivals for Split and Trogir in 2017. and 2018.

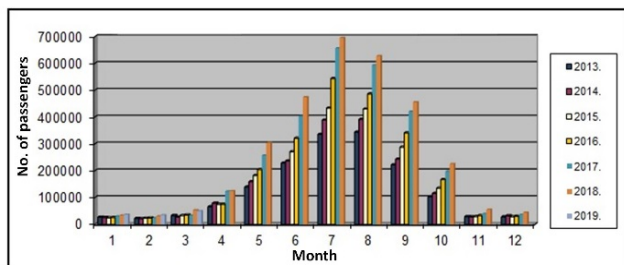Figure 1. Split center traffic congestion in summer season (source: Jutarnji List)

Figure 2. Number of airport passengers through months for the period from January 2013. to March 2019 (source: Split Airport)
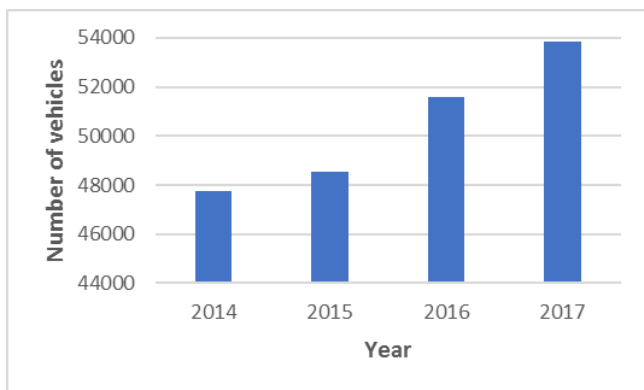

Figure 3. Average summer daily traffic – measured at the entrance of Split – northwest (source: Hrvatske ceste)
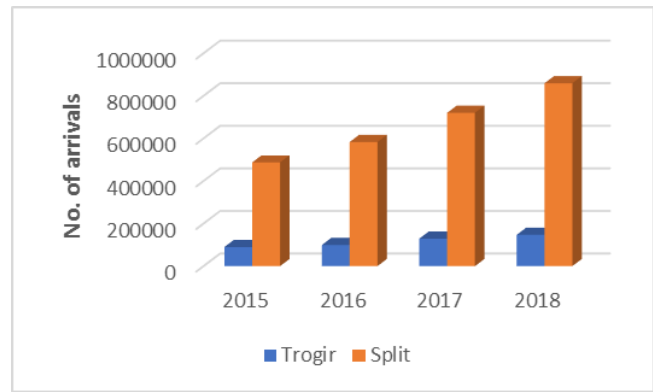

Figure 4. Number of arrivals for Trogir and Split (source: Croatian bureau of statistics)

To reduce road traffic in the area of Kaštela and Split center which can be done by reduction of taxi and rent-a-car transfers from Trogir to Split and from airport to Split, in this paper alterative path is proposed.

The transfer of tourist from airport to Split can be done by electric catamaran. Electric catamaran is a vessel whose propulsion and control system consist of electric motors, battery packs, charge/discharge controllers, inverters, photovoltaic panels and other loads (lightning, navigation, communication).

The idea of marine transfers is not new. At the airport there are stands at which one can find taxi boats and rent-a-bots. The ferry port Divulje is approximately 800 m from the entrance into the building of the airport. The first catamaran line from center of Split to Resnik (ferry port Divulje) will start with May 1st 2019. Figure 5 shows the catamaran that will be used from center of Split to Resnik.

Figure 5. Catamaran that will be used for Split – Resnik line (source: Catamaran line d.o.o. Split)

Length overall of this catamaran is 26.65 m, beam 9.00 m, draught 1.20 m and the capacity is 145 passengers.

This catamaran will reduce the number of vehicles but its propulsion system is based on diesel-engine technology. Electric catamaran would use the energy from the electrical grid. Since electrical energy in Dalmatia comes from five hydropower plants the catamaran would use "green" energy.

2 ELECTRIC CATAMARAN – ELECTRICAL SYSTEM

In this paper two electrical systems are presented. Electrical system of electric catamaran presented by

Spagnolo (Spagnolo et al., 2012) and Sunaryo (Sunaryo, Ramadhani, 2018). Figure 6a shows the electrical system for catamaran presented by Spagnolo (Spagnolo et al., 2012) and Fig 6b shows electrical system presented by Sunaryo (Sunaryo, Ramadhani, 2018).
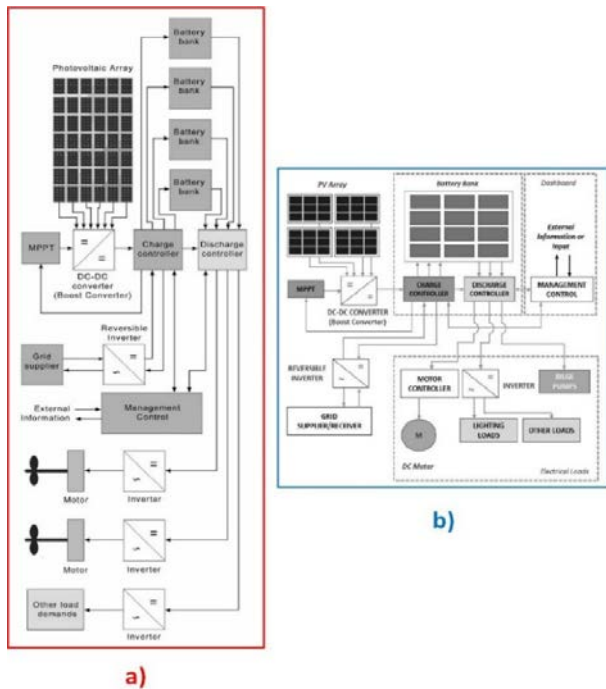

Figure 6. Catamaran electrical system: a) Spagnolo b) Sunaryo (source: Spagnolo et al., 2012 ; Sunaryo, Ramadhani, 2018)

Components of electrical system are:
– Photovoltaic array
– Battery bank
– DC/DC converter (Boost converter)
– Charge/discharge controller
– MPPT (Maximum power point tracking)
– AC/DC converter
– DC/AC converters
– Electric motors
– Management control
– Grid supplier
– Other loads (lightning, navigation, communication, accommodation)

Basically, systems from Fig. 6a and Fig. 6b are the same. In Table 1 the characteristics of catamarans are shown.

Table 1. Catamaran characteristics (source: Spagnolo et al., 2012; Sunaryo, Ramadhani, 2018)

Characteristics	Spagnolo	Sunaryo
Length overall	14.00 m	12.64 m
Beam	5.50 m	5.39 m
Draft	0.9 m	0.7 m
Maximum speed	15 km/h ≈ 8 knots	11 km/h ≈ 6 knots
Cruising speed	8 km/h ≈ 4 knots	8 km/h ≈ 4 knots
Electric motor	2 x 8 kW (PMSM)	1 x 4.9 kW (DC)
PV array area	≈ 55 m²	≈ 58 m²
No. of PV panels	42	58
Panel W_{Pmax} (STC)	225 W	140 W

3 PROBLEM STATEMENT

The first commercial catamaran on the route Split – Airport (Resnik) will start operating on May 1st 2019. Out of season this catamaran will daily cross this route 16 times and during season, number of crossings will be 20. Figure 7 shows the route on which the catamaran will operate (black line).

Figure 7. Geographical position of Trogir, airport, Kaštela (thick red lines), Solin and Split with proposed catamaran line Split – Resnik (Airport) (thick black line) (source: Authors)

The distance according to *Google Maps* is approximately 12 km (or 7.3 NM). It is stated that this catamaran will make one crossing in 20 min with average speed of 36 km/h (≈ 20 knots).

Getting to airport from the same starting point in Split by car, takes approximately 30 min. But during the summer season, the traffic congestion in Split center will make this trip 30 to 45 minutes longer.

To compete with conventional transport, this paper proposes electrical catamaran that can transfer the passengers from center of Split to airport (Resnik) in 30 min. To achieve this crossing time average speed of the catamaran must be 24 km/h (≈ 13 knots).

From Table 1 it can be seen that electrical catamarans presented cannot be taken into consideration because their maximum speeds are lower than 13 knots. In next section 1 passenger ferry, 1 air supported vessel and 3 electrical catamarans are presented.

4 ELECTRICAL VESSELS – OVERVIEW

4.1 *"Future of the Fjords"*

"Future of the Fjords" is the first of its kind all-electric passenger catamaran. It is designed to take 400 passengers on the 90 minutes, each way, trip twice a day from Flam to Gudvangen (23 NM, nautical miles). Hull is constructed from carbon fiber composite. Electric propulsion, delivered by two 450 kW motors, is powered from 1.8 MWh battery pack enabling cruising speed of 16 knots. Ship is docked in Gudvangen on a 40 m long and 5 m wide floating glass fiber dock, housing a 2.4 MWh battery pack providing the 20-minute fast charging capability for the ship. This charging dock is connected to the local grid network and charges up steadily throughout the day.

Figure 8. Electric catamaran "Future of the Fjords" (source: DNV GL)

Table 2. "Future of the fjords" Facts

Length	42 m
Width	15 m
Material	Carbon fiber sandwich
Seats	400
Propulsion	2 x 450 kW
Battery	1800 kWh
Cruising speed	16 knots
Range	30 NM

4.2 "E/S Sjövägen"

It is an electric ferry which transports up to 150 passengers eight times a day on a 10 NM public transport line. It is made out of sandwiched PVC composite material and is ice reinforced. Electric propulsion is provided by two 160 kW electrical motors on double propeller system enabling cruising speed of 10 knots. Its 500 kWh battery bank are fully charged during the ferry's overnight stay at the dock, with two partial charging sessions during the day.

Figure 9. "E/S Sjövägen" electric ferry (source: B/F Sjövägen)

Table 3. "E/S Sjövägen" Facts

Length	24.55 m
Width	7 m
Material	PVC composite sandwich
Seats	150
Propulsion	2 x 160 kW
Battery	500 kWh
Cruising speed	10 knots
Range	12 NM

4.3 Electric ASV vessel "BB Green Airi El"

This ship is designed for short routes (5 – 14 NM) at high speeds (30 knots). Its unique hull design, made out of carbon fiber sandwich, based on ASV (Air Supported Vessel) technology reduces hull water resistance by 40%. Most of the vessel's weight is supported on a cushion of air provided by electric lift fan system. Electric propulsion is provided by two 280 kW permanent magnet motor with additional 50 kW motor for ASV lift fan system. Ship is designed to carry 400 kWh battery pack while for prototype vessel half the battery pack will be used. For commercial use recharging the battery in less than 30 minutes and operating on hourly schedule may be possible.

Table 4. "BB Green Airi El" Facts

Length	20 m
Width	6 m
Material	Carbon fiber sandwich
Seats	70
Propulsion	2 x 280 kW; 1 x 50 kW
Battery	400 kWh
Cruising speed	30 knots
Range	12 NM

Figure 10. "BB Green Airi El" electric ASV vessel (source: BB Green)

4.4 Electric catamaran "Niko Nodilo"

This electric catamaran is designed to operate in vulnerable environment. This ecologically sensitive ship will replace the older fleet that operated as ferries around the larger lake in the middle of the "Mljet" National Park. Hull is made out of composite sandwich material, 15 meters long and 5 meters wide, carrying 54 passengers and 2 crew members. Electric propulsion is provided by two 12kW permanent magnet motors which enables cruise speed of 5 knots. A 7.5 kW solar power plant, installed on the roof, provides a daily autonomy of 8 hours at cruise speed during the summer months. Power is provided by 50 kWh LiFePO4 battery pack charged by onboard solar plant or onshore local grid.

Figure 11. "Niko Nodilo" electric catamaran (source: Pomorac.Net)

Table 5. "Niko Nodilo" Facts

Length	15 m
Width	5 m
Material	Composite sandwich
Seats	54
Propulsion	2 x 12 kW
Battery	50 kWh
Cruising speed	5 knots
Range	40 NM

4.5 "Solarwave solar catamaran"

This electric powered catamaran is designed to carry 50 passengers. It is made out of PVC sandwich E-glass and is 17.8 meters long and 6 meters wide. Electric propulsion is provided by two 9 kW electric motors powered from 60 kWh battery bank. Approximate power consumption at cruising speed of 6 knots is 12 kW/h. Charging is done by 10 kW onboard solar power plant installed on the roof or connecting to onshore local grid.

Figure 12. "Solarwave solar catamaran" (source: Solarwave Yachts)

Table 6. "Solarwave solar catamaran" Facts

Length	17.8 m
Width	6 m
Material	PVC sandwich
Seats	50
Propulsion	2 x 9 kW
Battery	60 kWh
Cruising speed	6 knots
Range	30 NM

For comparison in Table 7 the cruising speed, battery capacity, no. of seats and total propulsion power of all vessels are shown.

Table 7. Comparison of vessel characteristics

	Cruising Speed [knots]	Propulsion [kW]	Battery capacity [kWh]	Seats
Future of the Fjords	16	2 x 450	1800	400
E/S Sjövägen	10	2 x 160	500	150
BB Green Airi El	30	2 x 280; 1 x 50	400	70
Niko Nodilo	5	2 x 12	50	54
Solarwave solar catamaran	6	2 x 9	60	50

5 SOLAR POTENTIAL

Croatian yearly sum of global irradiation for horizontally mounted PV modules is shown on Fig. 13. Only global horizontally irradiation is taken into consideration because in this paper it is assumed that all PV panels are mounted on the roofs which are flat and parallel to the ground or the sea surface.

Figure 13. Yearly sum of global irradiation (source: Photovoltaic geographical information system)

Yearly average energy obtained by PV system (Spagnolo et al., 2012; Omar, Mahmoud, 2019):

$$E = P_{PV} \cdot PSH \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \qquad (1)$$

where: E [kWh/year] – yearly average energy; PSH [h/year] – peak sunshine hours; P_{PV} [kWh]– PV array peak power; k_1 – coefficient for compensation for temperature effect; k_2 – coefficient which takes stains and wear into consideration; k_3 – coefficient that takes the loss of DC circuits into consideration (PV array); k_4 – coefficient that takes DC/DC converter losses into consideration.

Peak sunshine hours (Mahmoud, 2003):

$$PSH = \frac{E_{year}}{G_o} \qquad (2)$$

where: E_{year} [(kWh/m²)/year] – yearly average solar radiation intensity; G_o [W/ m²] – peak solar radiation intensity (= 1000 W/m²).

For the route from Split (center) to airport (Resnik) the targeted cruising speed is 13 knots. From Table 7 only two vessels fulfil this demand: "Future of the Fjords" and "BB Green Airi El". "Future of the Fjords" does not have PV panels and from Fig. 8 it can be seen that its design does not have flat surfaces that would be suitable for PV array installation. "BB Green Airi El" also does not have PV panels but it has relatively flat roof that provides possibility for PV array installation (Fig. 14).

Figure 14. "BB Green Airi El" with PV panels array on its roof (source: Transport Research and Innovation Monitoring and Information System)

Calculation of daily solar energy is made for "BB Green Airi El" and "Future of the Fjords" regardless

of its roof design. In this paper it assumed that area of PV array takes 70% of the overall surface (S=Length x Width) of the vessel. For the calculation, SunPower's panel SPR-X21-345 is taken into consideration. The area of one panel is 1.63 m² and its nominal power is 345 W (SunPower). Yearly average solar radiation intensity for area of Kaštela is 1650 [(kWh/m²)/year] (Fig. 13).

Coefficients from Equation 1: k_1=0.9; k_2=0.9; k_3=0.95; k_4=0.95. In Table 8 the average solar energy production for "BB Green Airi El" and "Future of the Fjords" is shown.

Table 8. Solar energy production

	S [m²]	70% S [m²]	No. of panels	E [$kWh/year$]	E_{day} [kWh/day]	(Batt. capacity/E_{day}) [%]
A	120	84	51	21229	58	14.5
B	630	441	270	112357	308	17.1

A= "BB Green Airi El"; B= "Future of the Fjords"

5.1 Energy consumption and economics

Table 9 shows the estimation of total energy consumption of "BB Green Airi El" and "Future of the Fjords" for one crossing. Total energy consumption is the sum of the propulsion motors and the other loads consumption (Krčum et al., 2018). For this calculation the assumption is that 20% of total battery capacity is consumed by other loads.

Table 9. Energy consumption

	Cruising Speed [knots]	Split – Resnik [NM]	Crossing time [min]	Consumption [kWh]		
				Propulsion	Other Loads	Total
A	30	7.3	15	152.5	80	232.5
B	16	7.3	27.6	414	360	774

A= "BB Green Airi El"; B= "Future of the Fjords"

With 20% assumption for other loads, from Table 9 it can be seen that "BB Green Airi El" needs charging at both docks (one charge for one crossing). "Future of the Fjords" needs charging at one dock (one charge every two crossings).

The number of crossings is taken with assumption that 30 minutes is enough time to recharge the batteries for next one or two crossings. The number of crossing along with number of seats gives the maximum number of passengers per day (Table 10). Also, it gives daily energy consumption. For basic economic analysis, maximum number of passengers per day along with the price of the one-way ticket is the income. Total energy consumption is the item of the expense calculation.

Table 10. Basic economic indicators for summer season

	June 1st – September 30th No. of crossings	No. of seats	Max. no. of passengers per day	Total energy consumption per day [MWh]
"BB Green Airi El"	20	70	1400	4.65
"Future of the Fjords"	16	400	6400	12.4

6 CONCLUSION

With growing tourist sector, there is an increase in road traffic between Split and the airport. The area between Split and the airport, city of Kaštela, experiences increase in air pollution. In this paper the alternative path is proposed with the purpose to decrease the road traffic and Split center congestion. Marine traffic on this relation is not new but there are no organized transfers for larger number of passengers with economically eligible ticket prices. From May 1st 2019. The first organized transfers by diesel catamaran will start with operation. To fully exclude the air pollution from marine traffic, in this paper the electric vessels are investigated. Overall seven vessels are presented in the paper. To compete with road traffic and new catamaran line the minimum cruising speed of the electric vessel is set to be 13 knots. From presented vessels two of them satisfy this speed value. These vessels are two very different vessels. They differ in cruising speed, installed battery capacity, propulsion power, overall dimensions and number of seats.

The conclusion itself is that there are commercially available electric vessels for the rout Split – airport (Resnik) with minimum cruising speed of 13 knots. But the question is, are these vessels along with the service they provide cost effective.

Depending on the energy consumption and battery capacity there can be one charging station or two charging stations. One charging station means lower infrastructure costs and lower maintenance cost but in the case of malfunctioning there is no backup supply except if there are battery pack at the station.

The cruising speed, number of crossings, energy consumption, number of seats, one or two charging stations, charging stations with or without battery pack are all items that should be taken into consideration to optimize the vessel for the route Split – airport (Resnik). Which in the end leads to another conclusion that custom solution may be needed.

Economic cost-effectiveness of this proposal will be subject of our future work.

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