Traffic & Transportation

Green Perspective of Air Cargo Transport Chains – The Case of Eastern Adriatic Region

Bojan BEŠKOVNIK

Original Scientific Paper
Submitted: 10 July 2023
Accepted: 5 Oct. 2023

bojan.beskovnik@fpp.uni-lj.si, Faculty of Maritime Studies and Transport, University of Ljubljana

Publisher:
Faculty of Transport and Traffic Sciences, University of Zagreb

ABSTRACT

This article deals with the highly topical issue of greening air transport chains. It is important to consider the environmental aspect of the current performance of air transport in regions with less intensive air transport chains, such as the Eastern Adriatic. The regional airports of Ljubljana, Zagreb and Belgrade are dependent on European air cargo hubs and at the same time have the task of connecting the national airports in Sarajevo, Podgorica, etc., which complicates the functioning of air transport chains regionally. A comprehensive consideration of air cargo chains is important in terms of price and transport time, but also in terms of the GHG footprint. The results show that an environmental assessment of air transport chains is necessary for a more comprehensive decision on sustainable supply chains. The study enriches the scientific understanding of air transport chains in the Eastern Adriatic region from the point of view of carbon footprint and energy efficiency of transport, and highlights the need to use the already developed IT tools in the assessment and modelling of transport chains when different options are presented to cargo owners. Integrating the above approaches and data into current business models enables the gradual regional decarbonisation of air transport.

KEYWORDS

air transport; transport chains modelling; sustainable air transport assessment; greenhouse gas (GHG) emissions; Eastern Adriatic airports; road feeder service.

1. INTRODUCTION

Global air transport plays a key role in the global economy, enabling the fast and efficient flow of goods and services around the world. Air transport is important for the development of companies and the achievement of business competitiveness. According to IATA [1], one-third of the total value of cargo carried worldwide is transported by air. Although air cargo transport has been subject to various fluctuations in recent years related to the global economic situation and various challenges in the aviation industry, its role in intercontinental transport is becoming increasingly important. In the years leading up to the COVID-19 pandemic, air cargo traffic increased, largely due to the growth of global trade and e-commerce. Kupfer et al. [2] point out that intense economic growth and increasing demand are influencing the short-term increase in air cargo traffic. Companies are striving to shorten delivery times and improve their competitiveness. Air cargo companies are focusing on increasing air transport capacity with larger aircraft and new connections between airports. This, in turn, requires additional fuel consumption and thus a higher proportion of greenhouse gas (GHG) or CO_2 emissions, which is likely to continue in the future [3]. In any case, EASA [4] expects that CO_2 emissions should decrease by 8% until 2050 from better air traffic management operations and by 42% from cleaner aircraft engines.

There is strong competition between European cargo airports, as they are relatively close to each other and connected by a very well-developed road infrastructure. Airports are divided into two main groups: main or hub airports and regional or feeder airports. Main airports provide direct air connections that allow a direct flight from the origin airport to the destination one [5]. Such transport is the most efficient and fastest, but it can be challenging for airlines to ensure a sufficient amount of cargo. This is precisely why regional cargo airports are important in providing cargo to hub airports. This introduces the "hub-and-spoke" models that allow both categories of airports to develop and operate, with both airports and airlines competing for as many strong regional connections as possible. These connections can be by air or by road. Road connections made by airlines on scheduled services are part of the Road Feeder Service (RFS) and are included by airlines in carriage under the Airway Bill [6]. Such connections are increasing in the European market [7], with airlines developing effective approaches to successfully manage RFS through certain hub airports, including from the perspective of reducing GHG emissions [8]. However, the fragmentation of air transport chains into different airport hubs makes it difficult to establish an airport hub that would be more environmentally efficient for a single European region. This is also the challenge for the Eastern Adriatic region.

In addition to the development guidelines for direct connections between airports and more modern aircraft, the entire aviation industry is under the influence of sustainability and environmental challenges. IATA [9] has set a goal for the aviation industry to be carbon-free by 2050, which will require coordinated action among the various sectors of the aviation industry, where EASA and ICAO take a leading role. The EASA Sustainable Aviation Programme streamlines certification and standardisation activities to provide industry and stakeholders with the guidance and instruments needed to meet future environmental challenges [10]. Environmental awareness and efforts to reduce the carbon footprint have led to the development of alternative fuels and sustainable approaches to aviation, as each new generation of aircraft reduces GHG emissions by 25% [11]. Aviation needs to join the other transport sectors that have already done much to decarbonise transport. Even if logistics companies are not the main actor in decarbonising commercial air transport, they select and recommend the transport route and logistics services for cargo owners. They play an indirect role in evaluating and comparing different transport chains, enabling cargo owners to make business decisions that should be sustainable in the future and emit less GHG. In fact, air cargo transport accounts for about a quarter of the aviation industry's GHG emissions, so it is important to thoroughly evaluate the possibility of greener air cargo transport chains.

Thus, the study aims to understand and analyse in depth the complex operation of air cargo transport chains, which not only rely on direct intercontinental air cargo connections between hubs, but also depend on the efficiency of RFS. The study takes a closer look at air connectivity and GHG emissions, as well as the energy efficiency (EE) of air cargo transport, based on the operation of RFS in the European market. Spatially, the study is located in the SE Europe or Eastern Adriatic region, where region airports are dependent on the European cargo hubs and the airlines that operate RFS from them. These airports also act as direct competitors in the market as they serve several countries in the region, namely Serbia, Croatia, Slovenia, Bosnia and Herzegovina, Montenegro and North Macedonia, through established efficient road transport links. Due to the diversity of air and land connections, cargo owners and logistics companies have a variety of options to organise the transport of air cargo shipments. Two hypotheses were made, consistent with the study's research points – hypothesis H1: the cheapest air transport from Asia to the Eastern Adriatic airports is not the most environmentally friendly, and auxiliary hypothesis H2: there are opportunities to reduce GHG emissions if alternative air transport services were established. The results of the study highlight the importance of environmental assessment of air cargo transport chains, as there are significant differences between them, of which cargo owners should be aware. Only then will they be able to manage their own green supply chains more comprehensively and contribute to the decarbonisation of international transport. This research contributes to the science by proposing more comprehensive data collection, analysis and transparency so that more efficient sustainable transport business processes and models [12] can be developed for the gradual regional decarbonisation of air transport.

2. LITERATURE REVIEW ABOUT RESEARCH PROBLEM

Green transport chains are an important challenge of the modern approach to the organisation of transport logistics, which is why they are the subject of extensive research in various fields such as infrastructure construction, sophisticated means of transport, fuels, transport planning, etc. Nowadays, transport planning takes into account the components of price, transport time, reliability and increasingly the environmental impact of transport [13]. Similarly, environmental elements are increasingly considered in air transport planning. Anser et al. [14] analyse carbon pricing in air transport, which can significantly affect carbon footprint reduction. Hileman [15], Yilmaz and Atmanli [16], Janić [3, 17], Barke et al. [11] discuss alternative drivers for greener air transport, which IATA [9] highlights as an important building block for decarbonising the entire industry. Sustainable fuels and aircraft weight reduction [18] along with new technologies for aircraft operations, are expected to contribute 70–80% to the full decarbonisation of aviation by 2050 [5]. This is particularly important because CO_2 emissions from aviation are more harmful than those from other modes of transport, as only these are emitted at higher altitudes [19]. In addition to the aforementioned development approaches, Hu et al. [20] also emphasise the importance of combining the use of certain aircraft models between airports according to their fuel consumption and projected emissions, which can further reduce GHG emissions.

Besides air transport, road transport between regional airports also plays an important role in efficient air cargo transport. This allows hub airports to have a significantly wider network of connections to regional airports compared to passenger airports [21]. Indeed, the RFS replaces air connections that are less efficient for shorter distances and where there is a risk of insufficient cargo in a single transport operation. Beifert [5] points out that RFS provides the fast and flexible transport demanded by air transport customers. Since it does not require large capital investments and road infrastructure is typically the most developed land transport infrastructure, it is a good basis for the development of regional airports. Incorporating a green approach into the operation of the RFS increases the environmental impact of green transport, as truck cargo space of RFS is often less filled than other road cargo services (FTL – Full Truck Load or LTL – Less than a Truck Load), and the RFS also operates in tight time windows [22, 23]. The latter increase the emissions of air shipments, but still to a lesser extent than air connections to regional airports [5]. Feng et al. [24] point out the problems of air cargo transport in terms of booking reliability, which negatively affect the utilisation of cargo space and thus the increase in GHG emissions per tonne of transported goods. Logistics companies often book air cargo space for a longer period of time and pay for the secured space even when it is underutilised. In addition, Choi and Park [25] highlight the problem of changing cargo characteristics in air transport. From predominantly high-value goods that more easily cover the high costs of air transport, more and more goods are being transported that pursue other economic effects such as lower inventories and fast deliveries. Because of the positive cost effects along the supply chain, they can cover the higher costs of intercontinental transport. However, the question arises whether these goods are willing to pay more for low-carbon transport.

Existing studies look at various approaches to decarbonising air transport, but there is a lack of applied studies on how to move from an environmentally passive approach of forming air transport chains to a comprehensive approach. IATA points out that full decarbonisation requires improving operational efficiency, which includes planning and systematically informing air transport users. Demir et al. [26] note that an assessment of the environmental impacts from air transport is being conducted, but there is a lack of assessment of these impacts in the management of transport chains. Zhou and Zhang [27] develop an emissions cost-based air transport planning model where operational decisions to reduce emissions result in higher transport costs. Finally, EASA works on environmental labelling scheme for informing passengers of the environmental impact of their flight options [28], which could be the basis for similar approaches in air cargo aviation industry. Moreover, EASA provides Aeroplane CO_2 Emissions Database for aircraft types as soon as their CO_2 certification is completed [29] and is hosting ICAO's Engine Emissions Databank which contains information on exhaust emissions of production aircraft engines, measured according to the procedures in ICAO Annex 16, Volume II.

Even if there are various tools and solutions for calculating GHG emissions, these are not used in commercial offers and in the valuation and breakdown of transport chains. The study fills the gap in understanding the existing way to collect and obtain data on the environmental impacts of present air transport chains, and highlights the need for a change in approach to inform cargo owners or transport organizers, as in most cases they receive bids that disclose only price and transport time (TT). In the "hub and spoke" system of air cargo transport chains, there are differences in price and TT, as well as GHG emissions and EE. Thus, using selected airports in the Eastern Adriatic as examples, the study comprehensively demonstrates the diversity of air transport and highlights the need for more comprehensive data presentation for regional green transition and sustainable development of air transport.

3. STUDY CASE AND RESEARCH METHODOLOGY

3.1 Methodology

The study focuses on the narrower scope of agile global supply chains, whose implementation relies on air cargo transport chains. Such chains ensure fast deliveries, reduce inventories and decrease the liquidity burden on the owners of the goods. The traditional approach to designing air transport chains is primarily based on matching the elements of price, transport time and availability of cargo space. When deciding on air transport, cargo owners currently focus most on these elements when forming supply chains. A more modern approach to designing sustainable air transport chains must also include an environmental assessment of each transport chain. Such an approach can be based on the use of already developed and available IT tools in the form of emission calculators. Air carriers or their GSAs can incorporate environmental and EE data into bids, allowing cargo owners or contracted forwarders to make a more comprehensive decision that includes elements of sustainable transport operations (*Figure 1*).

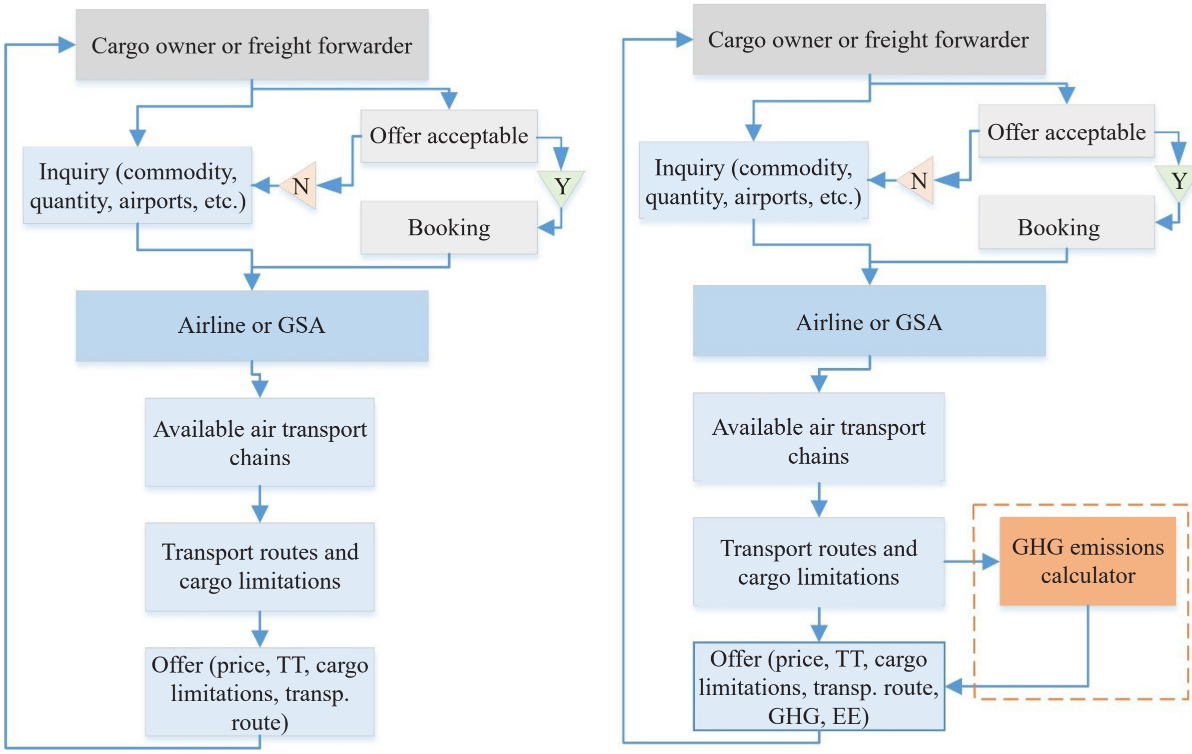


Figure 1 – Traditional approach vs. sustainable approach in planning air transport chain

Sustainable approach in planning air transport chain is contained in the study, which is geographically limited to the main air links between Asia and Europe or, more narrowly, between China and the major airports in the Eastern Adriatic region. A four-step research methodology was applied. First, the air cargo connections for the regional airports of Ljubljana, Belgrade, Zagreb and Sarajevo are analysed. The research approach also includes cargo transport with "belly cargo" passenger air services, which are available at major European hub airports [4] but allow the transport of shipments weighing up to one ton. Air services of this type in the region studied often do not allow the carriage of larger or heavier cargo shipments. Secondly, logistics companies were asked about the offers they receive from the GSA and the offers they make to cargo owners in order to understand the actual structure of the data available for air transport chain selection. The study was conducted in the first quarter of 2023. For air cargo shipments with a weight of one tonne and a volume of 0.86 m^3 from Shanghai, information about the airline, the size and type of the aircraft, the European hub airport, the implementation of RFS to the destination airport, TT and transport costs was requested. Namely, the technical and technological data on the type of air transport form the basis for calculating the environmental impact of moving a shipment by a single air cargo service.

In the next step, a specially developed tool ETW – EcoTransItWorld was used to calculate EE of transport and emissions of CO_2, SO_x, NO_x, PM10. The calculator allows calculating GHG emissions depending on the distance and type of transport. It uses the methodology defined in the ISO14083 standard and GLEC compliant calculations. The tool was developed by the independent scientific institutions Ifeu, Infras and Fraunhofer IML [30] and is used by many transport and logistics companies. The ETW Emissions Calculator was chosen because it is a useful tool for cargo forwarders and logistics companies, and provides a comprehensive calculation of GHG emissions and EE of multimodal transport chains when road (RFS) and air transport are combined sequentially. According to ETW, the calculator contains standardised interfaces (API) for the automatic emission calculation of large volumes of transport chains, ranging from semi-automatic calculations in CSV format to fully automated solutions based on a SOAP XML Web Service (WSDL). These solutions are already used by various global logistics companies and NVOCCs. Besides the mentioned tool, other IT tools or calculators are also used to calculate emissions from aviation, such as the ICAO Carbon Emission Calculator – ICEC [31], the IATA CO_2 connect calculator [32], etc., but ETW is more suitable for calculating GHG emissions from combined transport, where different means of transport from several transport sectors are used. Consequently, ETW provides logistics companies and cargo owners with a broader platform that can be directly linked to their operational program.

Finally, all air transport chains were compared in terms of price, TT, GHG emissions and EE. The results allow for the theoretical modelling of new nodes that would allow for a more environmentally sustainable operation of the air transport chains in the Eastern Adriatic region. Thus, calculations were made on the possible development of Budapest Airport as a central air transport hub and the carbon footprint savings achieved.

3.2 Data

The studied airports on the Eastern Adriatic achieve different yearly cargo throughput. Most of the cargo traffic is handled by Ljubljana airport (Jože Pučnik Airport). In 2022, about 30,000 tonnes of cargo were handled, which is an increase of 29.57% compared to the 2020 result, when the global economy was affected by the COVID-19 pandemic (*Figure 2*). Since 2015, the airport has recorded a 59.13% increase in cargo volume. Prior to the outbreak of the pandemic, the Belgrade airport (Belgrade Nikola Tesla Airport) experienced a significant growth in cargo, as cargo traffic increased by 84.25% between 2015 and 2019. However, after the pandemic, the airport recorded a significant decline. In 2022, the cargo volume amounted to 13,549 tonnes, which is comparable to the volume of cargo traffic in 2016. Zagreb Airport (Franjo Tuđman Airport Zagreb) is also a regional hub for cargo and passenger air traffic. In 2022, the airport handled 11,528 tonnes, which is 17% more than in 2020. In the period from 2015, the largest cargo volume was recorded in 2018, with 16,675 tonnes [33]. Overall, all three airports recorded the highest traffic volume in 2018, when it amounted to 59,647 tonnes alone. In 2022, the total traffic volume was 7.66% lower than in 2018 [34].

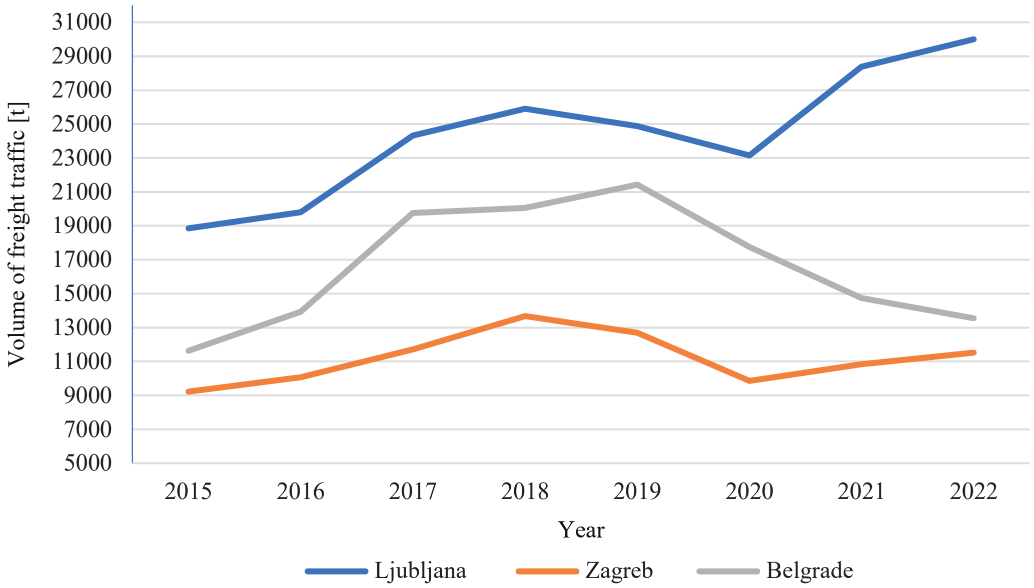


Figure 2 – Cargo volumes at Ljubljana, Zagreb and Belgrade airports (in tonnes)

In recent years, Ljubljana airport has undergone a major change with the bankruptcy of the national airline Adria Airways. The airline used Ljubljana airport as a hub and connected the Western Balkan region regionally through the airport. In terms of cargo traffic, about 60% of cargo is transported to the airport via RFS from European airport hubs (Frankfurt, Liege, Amsterdam, etc.). In 2021, 11,408 tonnes of cargo were transported by air, representing 40.19% of the airport's cargo volume. Of this, 97% of cargo was transported by regular flights and only 3% by extraordinary charter flights [35]. RFS is therefore an important component of airport operations. The same is true for Zagreb airport. Air cargo is also transported to this airport mainly through RFS, with the most active connections to Frankfurt, Liège and Amsterdam airports. When analysing connections from China, Belgrade airport has several options, including direct flights via Beijing and Istanbul, which are also used.

An overview of flight connections and transport prices from Shanghai for the airports studied shows the diversity of transport in terms of price and time. According to logistics companies for FOB (Incoterms Free on Board term) shipments weighing up to 1,000 kg and with a volume of 0.86 m^3, the prices of the five airline operators (AO) ranged from USD 3.6/kg to USD 7.4/kg (*Table 1*). TT also varies widely and is only 5 days for the shortest connection (AO4 service), while the longest TT is more than 10 days (offered by AO3). TT varies according to the European hub airport: AO1 uses Frankfurt, AO2 Amsterdam and Liège, AO3 Liège, AO4 Istanbul, while AO5 has a direct belly-cargo flight from Beijing to Belgrade. The AOs use different aircraft. The most common aircraft used is a Boeing 777F, while AO4 flies an A330-200F to Istanbul.

Table 1 provides data on the most frequently used air cargo services from Shanghai to Ljubljana, Zagreb and Belgrade airports, which are offered by logistics companies on a parity basis at FOB. There are no major differences for transport to Ljubljana and Zagreb, while several options are available for air transport to Belgrade, including direct air transport to Belgrade (services provided by AO4 and AO5). This also includes connections to Sarajevo (Sarajevo International Airport), which has no direct RFS connections to European hub airports, but is served by regional airports, mostly via Ljubljana.

Table 1 – Price, time and transport route from Shanghai to selected airports in the eastern Adriatic region

Dest. airport	Price [USD/kg]	TT	Operator	Transport route	Aircraft
LJUBLJANA (LJU)	3.6	7	AO1	Via Frankfurt & RFS	B777F
	3.9	9	AO2	Via Liege & RFS	B777F
	4.2	9	AO2	Via Amsterdam & RFS	B777F
ZAGREB (ZAG)	3.56	7	AO1	Via Frankfurt & RFS	B777F
	7.4	10	AO3	Via Liege & RFS	B747-400F
BELGRADE (BEG)	4.75	7	AO1	Via Frankfurt & RFS	B777F
	4.15	5	AO4	Via Istanbul & direct flight	A330-200F + A321Passenger
	3.6	8	AO5	RFS to Beijing & direct flight	A330-300
SARAJEVO (SJJ)	3.9	8	AO1	Via FRA & RFS via LJU	B777F
	4.35	8	AO5	Via IST + BEG & RFS	A330-200F + A321Passenger

The various air cargo services offer greater choice for cargo owners, who base their decision primarily on the cost of transport and the total delivery time of the shipment from China. The GHG emissions generated by the services and the EE of each shipment must also be considered, and the following parameters were used to calculate emissions and EE with the ETW calculator: air cargo space utilisation 60%, truck cargo space utilisation from RFS 70%, passenger space utilisation on belly cargo connections 65%, EURO 6 and EURO 5 (for Sarajevo) truck engine from RFS, while additional transport movements for truck transport between airports were not considered. For the theoretical comparison, the same parameters were used in the evaluation of all air transport chains, although the parameters vary between the different services.

4. RESULTS

The results of the research show the diversity of services, both in terms of price and time, and in terms of GHG emissions. The three air services studied for Ljubljana airport differ in terms of CO_2 emissions by up to 1.53% and similarly for EE by 1.24% (*Figure 3*). The most environmentally friendly service used by logistics companies is the service of AO1. The same service of AO for Zagreb, when transporting a shipment weighing 1 ton, causes 4.9 tonnes of CO_2 and consumes about 73,401 MJ of energy. The same is valid for the AO3 service, which is 1.57% less environmentally friendly and consumes 1.61% more energy. There are larger discrepancies in air cargo traffic to Belgrade. The AO1 service from the Shanghai airport produces the lowest CO_2 emissions (4.92 tonnes). The service organised by AO4 via Istanbul pollutes the environment 24% more, as CO_2 emissions exceed 6 tonnes. This service is also more wasteful from the perspective of EE. Compared to the AO1 service, 23.89% more energy is consumed. This flight service is particularly harmful to the environment in terms of PM10 emissions. Carrying one pallet weighing one tonne causes 42.42% higher emissions. The AO5 service is based on the belly-cargo service with the connection between Beijing and Belgrade. ETW does not have a direct connection parameterisation, so the connection via Warsaw is used just for the emission estimation. This service has a 12.91% larger carbon footprint. Energy consumption is also higher compared to the AO1 service. These are negative deviations of direct air transport, which are also highlighted by Beifert and Prause [6].

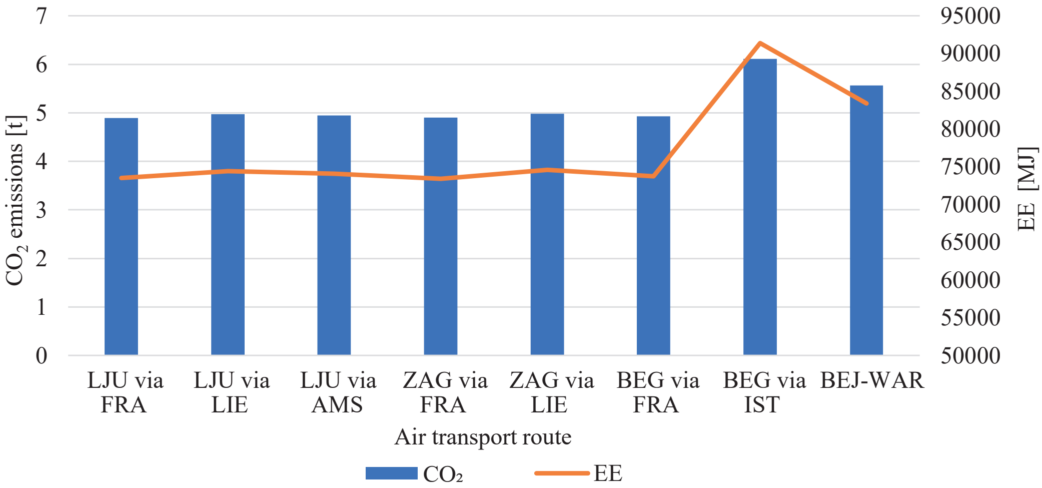
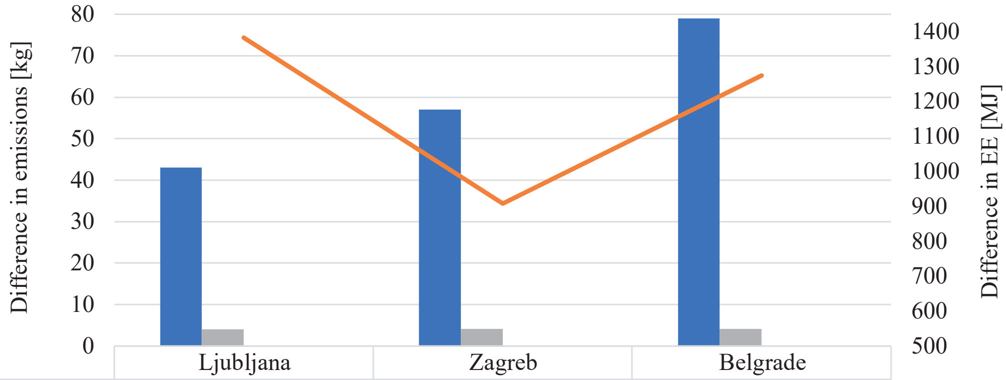


Figure 3 – CO_2 emissions and EE of mainly used air cargo services from Shanghai to selected airports

All three airports are fighting for the role of a regional hub that would effectively connect airports in the region such as Sarajevo, Podgorica, Skopje, etc. Therefore, the environmental impact of air services through all three regional hubs must also be evaluated from the perspective of regional air traffic development. For air transport from Shanghai to Sarajevo, the AO1 air route is used very frequently, which passes through Ljubljana airport. Such transport causes about 4.93 tonnes of CO_2, 24.36 kg of NO_x and 5.98 SO_x emissions. Similar emissions are generated when organising the AO1 transport via Zagreb and then by truck to Sarajevo. The price and time frame of such transport are very similar. If the cargo owners choose air transport via Belgrade with AO4 service and truck transport to Sarajevo, the price is 11% higher, while CO_2 emissions are even a quarter higher (24.36%). This transport route is also much more wasteful in terms of energy consumption, as the difference is a high 23.75%.

The results of the analysis of the most commercially represented transports from Shanghai to a single regional airport do not differ significantly. However, it should be emphasised that the airports in the Eastern Adriatic region are much closer to the airports in Budapest (Budapest Ferenc Liszt International Airport) and Vienna (Vienna International Airport), which have direct passenger flight connections with Shanghai and offer belly cargo services. The airports in Shanghai and Budapest are connected by regular air service, mainly using Boeing 787-9 aircraft. On the route from Shanghai to Vienna, various aircraft are used, including Airbus A350-900 and Boeing 777-200. The analysis of belly-cargo transport from Shanghai to Budapest and then with RFS to Ljubljana, Zagreb and Belgrade shows that the use of this type of transport does not significantly change the carbon footprint of air cargo transport at 90% utilisation of the cargo space (the maximum cargo capacity is only 10 to 15 tonnes). This mode of transport to Ljubljana generates 4.85 tonnes of CO_2, which is 1% (43 kg) less than the existing AO1 service. The EE is also 2% (1,383 MJ) lower than the AO1 service to Ljubljana (*Figure 4*). The same is true for the transport to Zagreb, as this service produces 1.2% less CO_2 emissions and is 1.2% more energy efficient than the AO1 service. However, it should be noted that the risks in reaching the cargo space are much more pronounced. This is because belly-cargo transport has a weight limit per individual transport, which may cause problems with cargo space on the booked flight. In addition, the service has no daily departures from Shanghai, which can further increase the overall TT.

As for environmental emissions via Vienna, there are differences between transports depending on the aircraft used. The transport with A350-900 causes less emissions for the same cargo space. Such a transport via Vienna to Ljubljana generates 5,086 kg of CO_2, which is 1.18% more than a belly-cargo transport via Budapest. A similar difference exists for EE and other GHG and PM10. A comparison of GHG emissions from Vienna to all three regional hub airports studied shows that emissions are almost the same due to the similar distance by road. The direction of air transport to other airports such as Sarajevo, Podgorica, Skopje, etc. then depends on the road distance, with Belgrade taking precedence over the analysed airports. The price of air transport with belly-cargo transport to Vienna and Budapest is about one third higher than the AO1 service in the period considered.



	Ljubljana	Zagreb	Belgrade
CO_2 [kg]	43	57	79
NO_x [kg]	4.09	4.11	4.13
SO_x [kg]	0.05	0.06	0.00
PM10 [kg]	0.00	0.00	0.00
EE [MJ]	1383	908	1274

Destination airport

Figure 4 – Belly cargo transport via BUD compared to the most environmentally friendly air cargo transport actually used from Shanghai

A comparison of the performance of air cargo transport from the Asian logistics hub airport in Shanghai to the airports in the Eastern Adriatic shows differences in transport costs and TT, while the differences in GHG emissions between the services to the selected airport are less pronounced. For example, the FOB price difference between the most popular air services from Shanghai to Ljubljana is 16.67% and 28.57% for TT. GHG emissions differ by 1.5% even when air transport to three different European hub airports is used. For air transport via Zagreb airport, the differences are greater in terms of price and duration of the entire transport. The price differences are up to 100%, and the TT is also up to 42% longer. Despite the large price and time differences in the existing services, there are no significant differences in GHG emissions between them. They are within 1.5%, as it is the case for Ljubljana. According to the obtained data, the transport of air cargo shipments to Belgrade Airport also differs in terms of price and TT. The prices of the most common services differ by 30%, and the difference in TT is up to 40%. In contrast to the connections to Ljubljana and Zagreb, there are larger differences in GHG emissions, as AOs offer a variety of air services, from those that fly directly to Belgrade to those that make the last part of the transport by using RFS. GHG emissions differ by up to 24%, and EE is also in this ratio.

5. DISCUSSION

Dedicated air cargo services are certainly the most trustworthy, both because of the accessibility of the airspace and the regularity of the services. A comparison of the three elements of price, time and GHG emissions shows that air transport via Frankfurt is more affordable for shipments to Ljubljana and Zagreb, which is otherwise 1% less green compared to belly-cargo transport via Budapest. Transport via Budapest is 32% and 34.69% more expensive, respectively, and has a lower departure frequency. This affects the longer TT, which is up to 42% longer to both airports compared to the cheapest transport. The savings in CO_2 emissions and EE are up to 1% and 1.9%, respectively. The cheapest transport to Belgrade is a quarter of the time shorter and less than a third cheaper than the more environmentally friendly belly-cargo transport via Budapest. However, the transport via Budapest is much greener, as it causes a 14.76% lower carbon footprint and achieves a 15% higher EE compared to the cheapest transport (*Figure 5*). According to the results of the research, it makes sense for cargo owners and logistics companies to route their own air transport chains through other European airports with direct freight connections, as only these are very competitive in terms of price and time, while being slightly less environmentally friendly. Beifert and Prause [6] also emphasise the advantage of focusing on RFS connections to hub airports compared to belly cargo services.

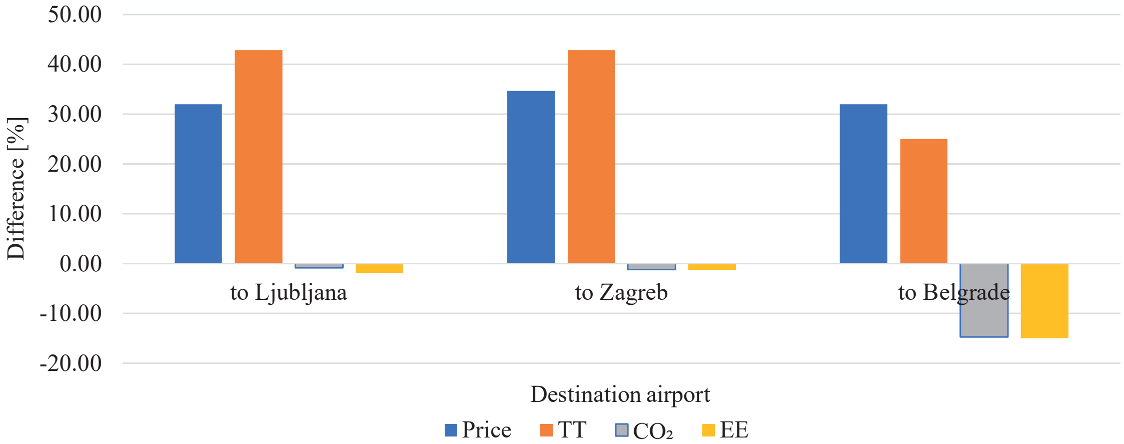


Figure 5 – Greenest vs. cheapest air cargo transport from Shanghai to selected airports

A direct air cargo line from Shanghai to Vienna or Budapest would make a significant contribution to greater unbundling of air transport chains in the Eastern Adriatic region. None of the AOs offer such a service because there is not enough cargo to establish a regular air cargo service. This would only be possible if the existing air transport chains were diverted from other European airport hubs. This is especially true for the markets of Slovakia, Austria, Hungary and the countries of the Eastern Adriatic. Using the same Boeing 777F aircraft and the same parameters for the utilisation of the aircraft's cargo space and truck transport from Budapest to the regional airports, such a transport chain would significantly reduce CO_2 emissions. Since the air cargo transport route to Budapest is shorter than to Frankfurt, the same cargo aircraft would cause less GHG emissions with the same load factor. According to the research results, the transport to Ljubljana Airport would produce 4.66 tonnes of CO_2 and very similar emissions to Zagreb and Belgrade airports (4.65 tonnes of CO_2), which is about 5% less than the CO_2 emissions of the current preferred services. Such air transport via Budapest to Ljubljana and Zagreb would also be 5.18% more energy efficient, i.e. about 3,800 MJ of energy would be saved for transporting the air shipment in question. NO_x, SO_x and PM10 emissions would also decrease by between 4.8 and 6.55% (*Table 2*).

Table 2 – GHG and EE reduction with direct cargo flight Shanghai – Budapest vs. actual used service

Destination airport	CO_2	EE	NO_x	SO_x	PM10
Ljubljana	4.84%	5.19%	6.40%	4.80%	4.69%
Zagreb	5.10%	5.18%	6.46%	5.05%	4.96%
Belgrade	5.52%	5.65%	6.55%	4.14%	5.30%

A comparison of the organisation of such a direct air cargo transport and RFS to Sarajevo also shows a greener transport. When organising the SHA-BUD-LJU transport to Sarajevo, the transport would generate 4.87 tonnes of CO_2. NO_x emissions would be 22.9 kg, SO_x emissions would be 5.69 kg and PM10 emissions would be 0.5 kg. At the same time, it would consume 70,279 MJ of energy, which is 4.82% less than the existing transport on the AO1 service. Savings in CO_2 emissions and EE would also be achieved in the case of rotation of air transport to Zagreb. CO_2 emissions would be 5.1% lower and EE 5.15% higher. Similar savings could be expected if air cargo shipments were transported via Belgrade, although there is a question about the price advantage, since transhipment is required in three different countries, only one of which is within the EU.

The results of the study should be considered as theoretical starting points for comparing air transport chains, as they are based on the assumption of equal cargo space utilisation on all routes. In addition, it does not take into account actual real data on the age and condition of aircraft on specific routes, which certainly has a significant impact on GHG emissions and the EE of air cargo transport. Proposals to establish a direct air cargo link to Budapest take into account the high utilisation of air cargo space, which could only be achieved by diverting existing cargo flows. The latter is difficult to realise due to the existing commercial and business base. Thus, these are only theoretical improvements that could provide more sustainable and acceptable transport operations in the longer term.

Taking into account the above assumptions, other European regions that do not have direct air cargo connections can be analysed in a similar way, looking for more favourable hubs for regional air cargo decarbonisation. This type of research would enable cross-comparability and provide insights into the possibility of gradual decarbonisation of air cargo transport based on reorganisation and redirection of transport chains.

6. CONCLUSION

Air cargo is the largest contributor to GHG emissions, measured by the tonne of cargo transported per kilometre travelled. Studies have shown that on average about 0.5 kg of CO_2 is generated, but for certain flights it can be more than 1 kg of CO_2 per tonne kilometre. Air cargo is thus responsible for about 25% of all GHG emissions from global air transport. Compared to maritime transport, it is therefore 50 or even 150 times less green. All the more reason to pay attention to the organisation of transport chains that rely predominantly on air transport.

This also applies to the transport chains formed through the airports of the Eastern Adriatic. Indeed, the results of the study show the diversity of air connections from China to European airport hubs and then RFS to regionally important airports such as Ljubljana, Zagreb and Belgrade. From here, further land connections are offered to national airports such as Sarajevo, Podgorica, Skopje, etc. The results show that the existing services differ in terms of price, time and environment. Therefore, it is important to inform cargo owners and their forwarders about GHG footprint that each air transport chain creates. According to the study, this is not common practise in the air cargo industry in the region. In addition, the study shows that there is an opportunity to use belly-cargo connections, which are not competitive in terms of price and time, but are more environmentally friendly. Based on the results of the study, the basic hypothesis H1 is confirmed that the cheapest flights from Asia to the airports of the Eastern Adriatic airports are not the most environmentally friendly.

Belly-cargo transports with high passenger and cargo space occupancy are more environmentally friendly, but less suitable from the point of view of lean and agile supply chains. The results for transport to Belgrade airport confirm the hypothesis even more, as the cheapest air cargo transport creates up to 14% larger carbon footprint and is 15% less energy efficient.

It is also possible to partially confirm the auxiliary hypothesis H2, i.e. there are opportunities to reduce GHG emissions if alternative air services are used. Opportunities for more environmentally sustainable services exist but are not yet established. Establishing an additional cargo hub at Budapest airport for air cargo shipments from Shanghai could reduce the carbon footprint by about 5%. EE would be improved by the same amount and SO_x and PM10 emissions would be reduced as well. Even NO_x emissions would be reduced by over 6%. In order to establish regular cargo flights from Shanghai to Budapest, the business and economic goals must first be achieved, which is extremely difficult. It is a question of consolidating capacities and business interests at the departure and destination airports and in the wider gravitational area of both airports.

The results of the study thus highlight the need to evaluate and present GHG emissions for each mode of transport offered by AO. Given the diversity of transport, such an assessment is important so that cargo owners can also base their decisions on sustainable transport and not just on price and time competitiveness. This encourages the establishment of new transport and business models that pursue sustainable business development, where independently developed GHG emission calculators can be used for single transport chain evaluation. Moreover, a more integrated regional approach at the European level can progressively reduce the carbon footprint of air cargo transport in the EU.

The study suggests changes in the management of air cargo transport chains, as the results show discrepancies in the economic and environmental assessment of transport chains. The results are a good and relevant starting point for further considerations on approaches for the assessment of air cargo transport chains in the Eastern Adriatic region. Thus, further development of the approach to modelling air transport chains considering GHG emissions is planned, using MCDA (Multi-Criteria Decision Analysis) and DEA methods in the assessment and weighting of the individual elements of air transport, in order to achieve more transparent approaches in the assessment of business decisions and decisions on the sustainable operation of supply chains. The latter will be the subject of further research on green and sustainable air transport chains.

ACKNOWLEDGMENTS

The study was conducted as part of the Program Research Group "Modelling and simulations in traffic and maritime engineering", funded by the Slovenian Research and Innovation Agency.

REFERENCES

[1] IATA. *The value of air cargo: Air cargo makes it happen*. https://www.iata.org/en/programs/cargo/ [Accessed 12th May 2023].

[2] Kupfer F, et al. The underlying drivers and future development of air cargo. *Journal of Air Transport Management*. 2017;61:6-14. DOI: 10.1016/j.jairtraman.2016.07.002.

[3] Janic M. Greening commercial air transportation by using Liquid hydrogen (LH2) as a fuel. *International Journal of Hydrogen Energy*. 2014;39:16426-16441. DOI: 10.1016/j.ijhydene.2014.08.011.

[4] EASA. *European aviation environmental report 2022*. https://www.easa.europa.eu/eco/sites/default/files/2023-02/EnvironmentalReport_EASA_summary_12-online.pdf [Accessed 27th Aug. 2023].

[5] Beifert A. Role of air cargo and road feeder services for regional airports—Case studies from the Baltic Sea region. *Transport and Telecommunication Journal*. 2016;17(2):87-99. DOI: 10.1515/ttj-2016-0008.

[6] Beifert A, Prause G. Integrating air cargo road feeder services into green transport corridors. In: Kabashkin I, Yatskiv (Jackiva) I, Prentkovskis, O. (eds.) *Reliability and Statistics in Transportation and Communication. Lecture Notes in Networks and Systems.* Springer, Cham. 2019. p. 409-420. DOI: 10.1007/978-3-030-12450-2_38.

[7] Selinka G, Franz A, Stolletz R. Time-dependent performance approximation of truck handling operations at an air cargo terminal. *Computers & Operations Research*. 2016;65:164-173. DOI: 10.1016/j.cor.2014.06.005.

[8] Baxter GS. Assessing the carbon footprint of a dedicated all-cargo airline: The case of Cargolux international airlines. *Journal of Urban and Environmental Engineering*. 2020;14(2):204-217. DOI: 10.4090/juee.2020.v14n2.204217.

[9] IATA. *Resolution on the industry's commitment to reach net zero carbon emissions by 2050*. https://www.iata.org/contentassets/dcd25da635cd4c3697b5d0d8ae32e159/iata-agm-resolution-on-net-zero-carbon-emissions.pdf [Accessed 10th Apr. 2023].

[10] EASA. *EASA's Sustainable aviation programme*. https://www.easa.europa.eu/eco/sustainable-aviation/topics/easas-sustainable-aviation-programme [Accessed 29th Aug. 2023].

[11] Barke A, et al. Are sustainable aviation fuels a viable option for decarbonizing air transport in Europe? An Environmental and Economic Sustainability Assessment. *Applied Sciences*. 2022;12(2):597. DOI: 10.3390/app12020597.

[12] Lößer L. A procedure model for low emission transportation chain planning. *Promet – Traffic&Transportation*. 2021;33(6): 893-904. DOI: 10.7307/ptt.v33i6.3935.

[13] Beškovnik B, Golnar M. Evaluating the environmental impact of complex intermodal transport chains. *Environmental Engineering and Management Journal.* 2020;19(7):1131-1141. DOI: 10.30638/eemj.2020.107.

[14] Anser MK, et al. The role of carbon pricing in the relationship between air freight and environmental resource depletion: A case study of Saudi Arabia. *Clean Technologies and Environmental Policy*. 2023;25:1461-1472. DOI: 10.1007/s10098-020-01844-9.

[15] Hileman IJ, Stratton WR, Donohoo EP. Energy content and alternative jet fuel viability. *Journal of Propulson and Power*. 2010;26(6):1184-1195. DOI: 10.2514/1.46232.

[16] Yilmaz N, Atmanli A. Sustainable alternative fuels in aviation. *Energy*. 2017;140(2):1378-1386. DOI: 10.1016/j.energy.2017.07.077.

[17] Janić M. An assessment of the potential of alternative fuels for "greening" commercial air transportation. *Journal of Air Transport Management*. 2018;69:235-247. DOI: 10.1016/j.jairtraman.2017.09.002.

[18] Baxter G. Decarbonizing international air cargo transportation's carbon footprint: A review of the world air cargo carrying airlines current and potential environment related measures and strategies. *International Journal of Environment Agriculture and Biotechnology.* 2021;6(6):265-290. DOI: 10.22161/ijeab.66.31.

[19] Habib Y, et al. Testing the heterogeneous effect of air transport intensity on CO_2 emissions in G20 countries: An advanced empirical analysis. *Environmental Science and Pollution Research*. 2022;29:44020–44041. DOI: 10.1007/s11356-022-18904-w.

[20] Hu R, et al. Characteristics and mitigation measures of aircraft pollutant emissions at Nanjing Lukou International Airport (NKG), China. *Promet – Traffic & Transportation*. 2020;32(4): 461-474. DOI: 10.7307/ptt.v32i4.3280.

[21] Bombelli A, et al. Analysis of the air cargo transport network using a complex network theory perspective. *Transportation Research Part E: Logistics and Transportation Review*. 2020;138:101959. DOI: 10.1016/j.tre.2020.101959.

[22] Heinitz F, Hirschberger M, Werstat C. The role of road transport in scheduled air cargo networks. *Procedia - Social and Behavioral Sciences*. 2013;104:1198-1207. DOI: 10.1016/j.sbspro.2013.11.216.

[23] Berling P, Eng-Larsson F. Pricing and timing of consolidated deliveries in the presence of an express alternative: Financial and environmental analysis. *European Journal of Operational Research*. 2016:250(2):590-601. DOI: 10.1016/j.ejor.2015.09.041.

[24] Feng B, Li Y, Shen ZJM. Air cargo operations: Literature review and comparison with practices. *Transportation Research Part C: Emerging Technologies.* 2015;56:263-280, DOI: 10.1016/j.trc.2015.03.028.

[25] Choi JH, Park YH. Investigating paradigm shift from price to value in the air cargo market. *Sustainability*. 2020;12:10202. DOI: 10.3390/su122310202.

[26] Demir WE, et al. Methodological approaches to reliable and green intermodal transportation. In: Cinar D, et al. (eds.) *Sustainable Logistics and Transportation. Springer Optimization and Its Applications.* 2017. p. 129. DOI: 10.1007/978-3-319-69215-9_7.

[27] Zhou G, Zhang, Y. Integration and consolidation in air freight shipment planning: An economic and environmental perspective. *Journal of Cleaner Production*. 2017;166:1381-1394, DOI: 10.1016/j.jclepro.2017.07.145.

[28] EASA. Environmental Labelling Scheme for Aviation. https://www.easa.europa.eu/eco/aviation-environmental-label/topics/the-case-for-an-environmental-label-in-aviation [Accessed 28th Aug. 2023].

[29] EASA Aeroplane CO_2 Emissions Database. https://www.easa.europa.eu/en/domains/environment/easa-aeroplane-co2-emissions-database-0 [Accessed 28th Aug. 2023].

[30] ETW. Emission calculator. https://www.ecotransit.org/en/emissioncalculator/ [Accessed 18th Mar. 2023].

[31] ICAO. ICAO Carbon Emissions Calculator (ICEC). https://www.icao.int/environmental-protection/Carbonoffset/Pages/default.aspx [Accessed 27th Aug. 2023].

[32] IATA. IATA CO_2 Connect Calculator. https://www.iata.org/en/services/statistics/intelligence/co2-connect/iata-co2-connect-passenger-calculator/ [Accessed 28th Aug. 2023].

[33] Zagreb airport. Statistics. https://www.zagreb-airport.hr/en/business/b2b/statistics [Accessed 10th Apr. 2023].

[34] Bloombergadria. *Airfreight in the region*. https://si.bloombergadria.com/ekonomija/slovenija/21539/letalski-promet-v-regiji-beograd-z-najvec-potniki-brniku-tovorni-skalp/news/ [Accessed 15th May 2023].

[35] Stat.si. *Air transport in 2021*. https://www.stat.si/statweb/News/Index/10137 [Accessed 24th Apr. 2023].

Bojan Beškovnik

Zeleni pogled na transportne verige zračnega tovornega prometa: primer vzhodno jadranske regije

Povzetek

Članek obravnava zelo aktualno vprašanje ozelenitve verig zračnega prometa. Pomembno je upoštevati okoljski vidik trenutne delovanja zračnega prometa v regijah z manj intenzivnimi verigami zračnega prometa, kot je vzhodni Jadran. Regionalna letališča v Ljubljani, Zagrebu in Beogradu so odvisna od evropskih letalskih tovornih hub vozlišč, hkrati pa imajo nalogo povezovanja nacionalnih letališč kot so Sarajevo, Podgorica itd, kar otežuje delovanje transportnih verig zračnega prometa v regiji. Celovita obravnava verig zračnega prevoza tovora je pomembna z vidika cene in časa prevoza, vendar tudi z vidika odtisa toplogrednih plinov. Rezultati kažejo, da je okoljska ocena verig zračnega prometa potrebna za celovitejšo odločitev o trajnostnih dobavnih verigah. Študija bogati znanstveno razumevanje verig zračnega prevoza v vzhodno jadranski regiji z vidika ogljičnega odtisa in energetske učinkovitosti prevoza ter poudarja potrebo po uporabi že razvitih informacijskih orodij pri ocenjevanju in modeliranju prevoznih verig, ko so lastnikom tovora predstavljene različne možnosti. Vključitev navedenih pristopov in podatkov v sedanje poslovne modele omogoča postopno regionalno razogljičenje zračnega prometa.

Ključne besede

zračni promet; modeliranje transportnih verig; ocena trajnostnega zračnega prometa; emisije toplogrednih plinov (GHG); vzhodno jadranska letališča; cestni feeder prevoz.