



How the War in Ukraine Impacts Global Air Transportation Ecosystem: Assessment and Forecasting of Consequences

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Abstract. Russian invasion of Ukraine on 24th February 2022 leads to the restriction of air traffic in Ukrainian and Russian air spaces due to the military activity and war-related sanctions. Airspace closures have forced airlines to take detours and seek alternative routes. All these causes considerable increasing of flight time on routes connecting Europe and Asia, North America and Asia and North America and Middle East. In turns longer travel times lead to the increasing of aircrafts' fuel burn, which causes higher airlines operating costs and CO₂ emissions. This paper assesses the impact of the Russian invasion of Ukraine on the global air transportation ecosystem on the example of three European airlines, i.e. Finnair, LOT Polish and Lufthansa Airlines, analysing their most popular routes between Europe and Asia before and after flight restrictions. Performed analysis shows increasing of the airlines operations costs and CO₂ emissions from 18% to 40% on the certain routes after closure of air spaces. This research also contains a forecast of global aviation CO₂ emissions for the next five years under the two different scenarios of military conflict development on the territory of Ukraine, constructed with the help SARIMA Model.

Keywords: War in Ukraine · Global air transportation ecosystem · CO₂ emissions · Airline operating costs · Forecast

1 Introduction

On 24th February 2022 Russia invaded Ukraine just after aviation industry started to recover from COVID-19 pandemic. Immediately after Russia invasion Ukrainian air space was closed and all flights of commercial aviation were suspended for ensuring aviation safety and avoiding human losses. Being in solidarity with Ukraine, Great Britain, U.S., Canada and EU countries banned any transportation of Russian air carriers in their air space. In response to these sanctions, Russia limited the opportunities for airlines from 36 countries, including all 27 members of the European Union to cross its borders [1].

Ukraine comprises rather small part of the global air transportation market [2]. Its share of total air passenger traffic in Europe is 3.3%, and 0.8% in the world, as per 2021 [3] (Table 1).

Table 1. Traffic shares for selected markets impacted by the conflict.

% share of passengers numbers in 2021	Total European Traffic (excl. Russia domestic)	Global traffic
Russia International	5.7%	1.3%
Ukraine	3.3%	0.8%
Moldova	0.4%	0.1%
Belarus	0.3%	0.1%

Source: IATA Economics using DDG

However, the impacts of the war extend much beyond air travel to and from Ukraine. Closure of airspaces have forced airlines to seek alternative routes and take detours. This causes considerable increasing of flight time on routes connecting Europe and Asia, North America and Asia and North America and Middle East. In turns longer travel times lead to the increasing of aircrafts' fuel burn, which cause higher airlines' operating costs and CO₂ emissions. The effect of flights restrictions on European airlines have been different for various companies [4]. The impacts vary between airlines, depending on the location of hub airports, routes network and country of registration. The most affected European airline by Russian-Ukrainian war is Finnair, having a hub in Helsinki for connecting flights between Asia and Europe. Its proximity to the Russian Federation meant that for the most of its direct air routes to Asia, operated through Russian airspace, Finnair had to find alternative routes trajectories. For example, flights between Helsinki and Tokyo offered by Finnair, now take up to 3.5 h longer (see Fig. 1).

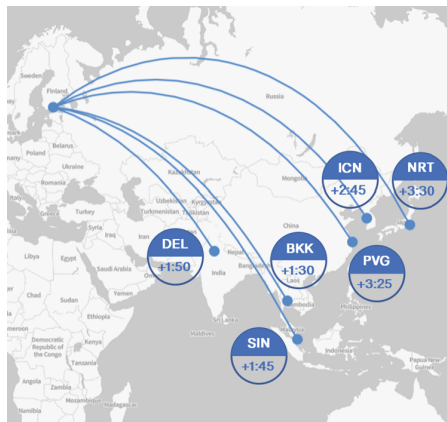


Fig. 1. Duration of the Finnair alternative routes from Helsinki to Asia after flights restrictions [4].

The airlines based in Asia have been less impacted by the conflict. They have not been barred from Russian airspace, but some of them (e.g. Japan Airlines, Korean Air, etc.) though overfly Russia.

The paper addresses the following research questions:

- **How much do airlines operating costs change** on the selected direct routes between Europe and Asia after flights restrictions due to the Russian invasion of Ukraine?
- **How much do airlines CO₂ emissions change** on the selected direct routes between Europe and Asia after flights restrictions due to the Russian invasion of Ukraine?
- **How global aviation CO₂ emissions will be changed in five years perspective** under two different scenarios of military conflict development of the territory of Ukraine (the war will end within one year or within three years)?

The paper’s findings help to better inform scholars and practitioners of extremely negative consequences of the Russian-Ukrainian conflict for aviation, which can prevent achievement of sustainable development goals in air transport within the established time frame [5, 6]. Moreover, the study makes a theoretical contribution to the research regarding the war impact on the aviation industry.

The paper is organized as follows. Section “Closed Ukrainian air space and global air traffic” analyses pertinent literature. Section “Research methodology” describes the paper’s research approach, developed to answer on the research questions. The analysis and discussion of findings regarding the impact of the war in Ukraine on the global air transportation ecosystem is presented in the section “Findings and discussions”, followed by the research conclusions in the section “Conclusion”.

2 Closed Air Spaces and Global Air Traffic

Ukrainian and Russian airways network comprise a huge part of global air transportation system. Closure of their airspaces causes serious problems for aviation (Fig. 2).

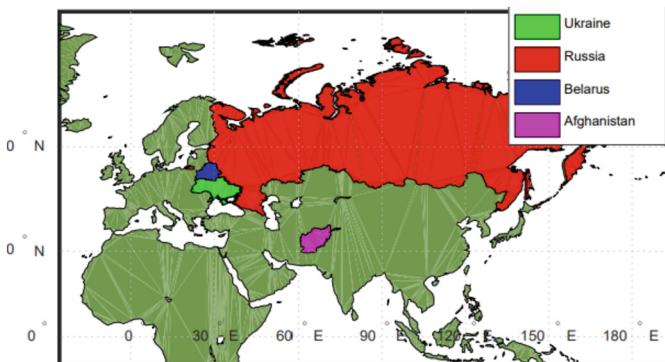


Fig. 2. Closed air space after Russian invasion of Ukraine [7].

The huge territory of Russia means large detours for many airlines overflying Russia during operation of their flights. This comprises more than 10% of pre-COVID-19

international traffic volumes, measured in RPKs, including travel from Europe to Asia (4.5%), North America to Asia (3.0%) and North America to the Middle East (4.0%) [8].

There are just a few research papers providing a preliminary estimation of the war impact in Ukraine on the global air transport. Ostroumov, I. Ivashchuk, O. and Kuzmenko, N highlighted in their papers [7, 9] that the geometry of closed airspace due to the military conflict in Ukraine seriously affects direct connections from Asia to North America and European countries as well as polar flights from North to South directions. Many flights have been cancelled due to closed airspace and special restrictions and trajectories of transit flights have been re-planned to overfly the territories of Russia and Ukraine [7] (Fig. 3).

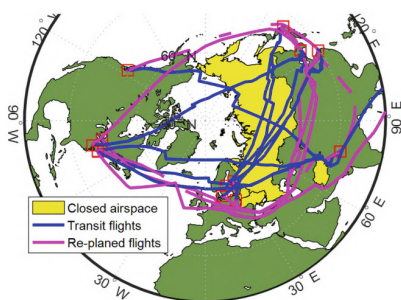


Fig. 3. Transit and replanned flights trajectories after Russia invasion of Ukraine [7].

Ostroumov, Ivashchuk and Kuzmenko [7, 9] provided a statistical analysis of scheduled air traffic losses inside Ukraine for different airlines due to the Russia-Ukrainian war as well as predicted for seven weeks the losses in total trajectories length, flight time, available seats, and available seat-kilometer for flights of different airlines, connected with closed Ukrainian airports.

The extent of literature featuring impact of the war in Ukraine on aviation is relatively constrained to the analysis of the increase in trajectory length and flight time. The changes of airlines operating costs and CO₂ emissions on the routes between Europe and Asia after flights restrictions due to the Russian invasion of Ukraine and also prediction of the changes in global aviation CO₂ emissions under the different scenarios of military conflict development on the territory of Ukraine have not been researched yet. This paper addresses found research gap.

3 Research Methodology

To assess impact of the war in Ukraine on the global air transportation ecosystem three questions have been researched:

1. **airlines operating costs** on the selected routes between Europe and Asia before and after flights restrictions due to the Russian invasion of Ukraine;
2. **CO₂ emissions** on the selected routes between Europe and Asia before and after flights restrictions due to the Russian invasion of Ukraine;

3. global aviation CO₂ emissions in the next five years under two different scenarios of the military conflict development on the territory of Ukraine.

Three European airlines, i.e. Finnair, LOT Polish and Lufthansa Airlines, operating direct flights from Europe to Asia have been selected as case studies. Fourteen different routes, operated by Chinese and European airlines, have been chosen for the investigation (see Table 2 and Fig. 4, correspondently). The initial data, used during routes analysis were obtained with the help of Flightradar 24 resource [10]. It is an internet-based service that shows real-time aircraft flight tracking information on a map, including origins and destinations, flight numbers, aircraft types, positions, altitudes, headings and speeds. The data presented in Table 2 show that at the moment there is a huge competition between European and Chinese airlines, specializing in the shortest routes between Europe and Asia. The competition is unequal as Chinese airlines have permission to fly within Russian air space, which give them advantages in flights time and routes distances (see Table 2).

The flights routes, having the most increased flight times now is the Finnair flights between Helsinki and Tokyo Narita Airport in Japan and Helsinki and Seoul Incheon Airport in South Korea, with the increase of the routes distances after flights restrictions on 39.9 and 49.3%, correspondently.

ACMIF_{*i*} (Aircraft depreciation AD_i , Crew CC_i , Maintenance M_i , Insurance I_i , Jet Fuel consumption F_i .) methodology was used for calculation of the airlines' operating costs of the selected single flights between Europe and Asia.

$$ACMIF_i = AD_i + CC_i + M_i + I_i + F_i, \quad (1)$$

Aircraft depreciation costs (AD_i) were calculated on the bases of a new aircraft price, depreciation rate and annual aircraft utilization. Crew costs (CC_i) consist of the costs of cabin and flight crew salary and allowances. Aircraft maintenance costs (M_i) consist of technicians' salary and spare parts costs (usually it is 10% of a new aircraft price per a year). Insurance costs (I_i) are a combination of aircraft insurance costs, crew members insurance and air carrier liability insurance. During calculations annual insurance rate was taken as 1.5%. Aviation fuel costs (F_i) were determined by applying the average hourly fuel consumption for each type of aircraft per the cost of 1 ton of fuel. The aviation fuel price in March 2023 was \$123 per barrel, which corresponds to 852.96 euros per ton.

Airline operating costs for a single flight (OC_{ij}) were calculated according to the following formula:

$$OC_{ij} = ACMIF_i \cdot t_j + AN_{ij}, \quad (2)$$

where t_j – flight time; AN_{ij} – airport and navigation fees.

CO₂ emissions on the selected routes before and after flights restrictions were determined using the ICAO Carbon Emissions Calculator Methodology in the specialized software [11, 12].

The final stage of the research was a forecast of the global aviation CO₂ emissions for the next 5 years under the two different scenarios of military conflict development on the territory of Ukraine, i.e.: First Scenario - Optimistic: war ends, airspace opens

Table 2. Characteristics of the investigated flights, between Europe and Asia.

No	Route	Airline	Flight number	Aircraft type	Flights frequency per a week	Route distance			
						Before restrictions, km	After restrictions, km	Difference, km	Difference, %
1	Helsinki (HEL) - Shanghai (PVG)	Finnair	AY87	A-350-900	2	7,636	10,666	3,030	39.7
2	Helsinki (HEL) - Shanghai (PVG)	Juneyao Airlines	HO1608	B-787-9	2	7,636	7,636	0	0.0
3	Helsinki (HEL) - Tokyo, Narita Airport (NRT)	Finnair	AY73	A-350-900	4	7,838	10,969	3,131	39.9
4	Helsinki (HEL) - Seoul (ICN)	Finnair	AY41	A-350-900	4	7,039	10,506	3,467	49.3
5	Warsaw (WAW) - Beijing (PEK)	LOT Polish	LO91	B-787-8	7	6,952	8,678	1,726	24.8
6	Warsaw (WAW) - Beijing (PEK)	Air China	CA738	A-330	2	6,952	7,534	582	8.4
7	Warsaw (WAW) - Tokyo, Narita Airport (NRT)	LOT Polish	LO79	B-787-9	6	8,623	11,062	2,439	28.3
8	Warsaw (WAW) - Seoul (ICN)	LOT Polish	LO97	B-787-8, B-787-9	4	7,734	9,606	1,872	24.2
9	Frankfurt (FRA) - Beijing (PEK)	Lufthansa	LH720	A-340-300	7	7,858	9,236	1,378	17.5
10	Frankfurt (FRA) - Beijing (PEK)	Air China	CA932	B-777-300	7	7,858	7,858	0	0.0
11	Frankfurt (FRA) - Tokyo, Haneda Airport (HND)	Lufthansa	LH716	B-747-8	6	9,379	11,469	2,090	22.3

(continued)

Table 2. (continued)

No	Route	Airline	Flight number	Aircraft type	Flights frequency per week	Route distance			
						Before restrictions, km	After restrictions, km	Difference, km	Difference, %
12	Frankfurt (FRA) - Seoul (ICN)	Lufthansa	LH712	B-747-400	7	8,554	10,101	1,547	18.1
13	Frankfurt (FRA) - Seoul (ICN)	Asiana Airlines	OZ542	A-350-900	7	8,554	10,110	1,556	18.2
14	Frankfurt (FRA) - Seoul (ICN)	Korean Air	KE946	B-777-300ER	5	8,554	10,112	1,558	18.2

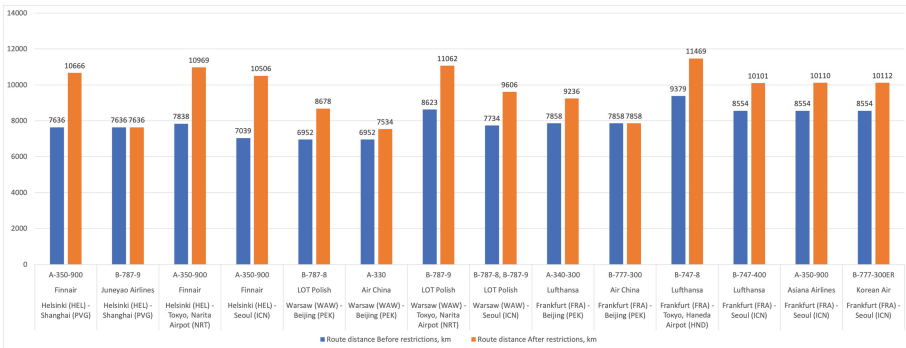


Fig. 4. Comparison analysis of the investigated flights routes distances before and after flights restrictions.

and air traffic restores within 1 year; First Scenario - Realistic: war ends, airspace opens and air traffic restores within 3 years.

Statistical data for determination of the forecasted volumes of the global aviation CO₂ emissions were taken from the www.statista.com (see Fig. 5) [13].

Time series forecasting is a difficult problem with not an easy answer. There are countless number of statistical models, used for forecasting, however it is never clear which model is best. One of the most frequently used time series model (due to its accuracy) is the autoregressive integrated moving average (ARIMA) model. The ARIMA model is described by the formula 3 below.

$$Y_t = \beta_2 + \omega_1 \cdot \varepsilon_{t-1} + \omega_2 \cdot \varepsilon_{t-2} + \dots + \omega_q \cdot \varepsilon_{t-q} + \varepsilon_t, \tag{3}$$

The main assumption made for this model implementation is that the considered time series is linear and follows a normal statistical distribution.

The ARIMA model consist of other subclasses, such as autoregressive (AR), moving average (MA) and autoregressive moving average (ARMA) models.

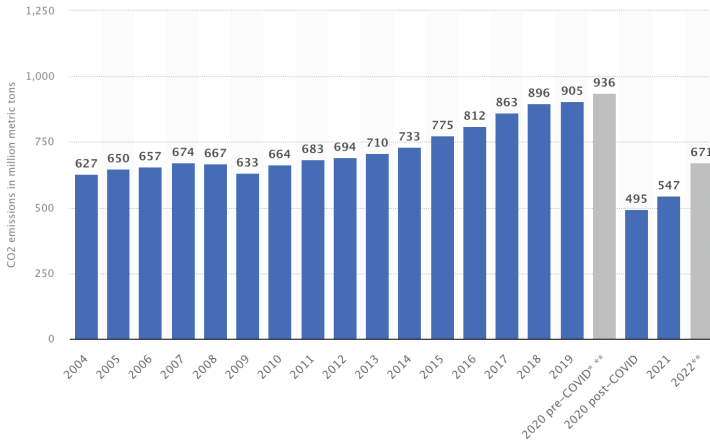


Fig. 5. Carbon dioxide emissions from commercial aviation worldwide from 2004 to 2022 [13].

For seasonal time series forecasting, which is more suitable for the aviation industry, characterised by cyclicity, there is a very successful variant of the ARIMA model – SARIMA (seasonal autoregressive integrated moving average) model. SARIMA model is described by the formula 4 below.

$$y_t = c + \sum_{n=1}^p a_n y_{t-n} + \sum_{n=1}^q \theta_n \epsilon_{t-n} + \sum_{n=1}^P \varnothing_n y_{t-sn} + \sum_{n=1}^Q \mu_n \epsilon_{t-sn} + \epsilon_t, \quad (4)$$

This model is quite similar to ARIMA one, except that there is an additional set of autoregressive and moving average components. Additional lags are offset by the frequency of seasonality. SARIMA models allow differencing data by seasonal and non-seasonal frequencies. The RStudio software was used for the development of different predictive scenarios for global CO₂ emissions using SARIMA model.

4 Findings and Discussions

This section presents results of calculation of Finnair, LOT Polish and Lufthansa Airlines operating costs and CO₂ emissions before and after flights restrictions on the selected routes between Europe and Asia. Figures 6, 7, 8, 9, 10, 11, 12, 13 and 14 provide the summary of the performed calculations.

Average Finnair Airline operating costs on the selected routes between Europe and Asia have been increased by 38.60% after flights restrictions, while average CO₂ emissions on the investigated routes have been increased by 40.15% after the restrictions of flights (see Fig. 6–8).

Average LOT Polish Airline operating costs on the selected routes between Europe and Asia have been increased by 23.29% after flights restrictions, while average CO₂ emissions on the investigated routes have been increased by 23.57% after the restrictions of flights (see Fig. 9, 10 and 11).

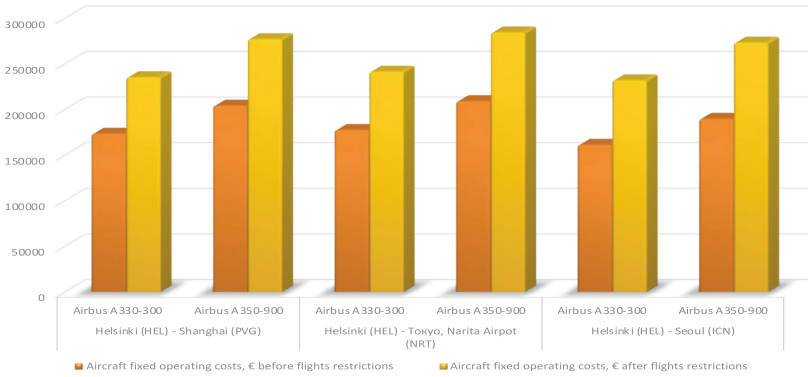


Fig. 6. Airline’s operating costs on the investigated routes before and after flights restrictions during operation of different types of aircraft: A Case of Finnair Airlines.

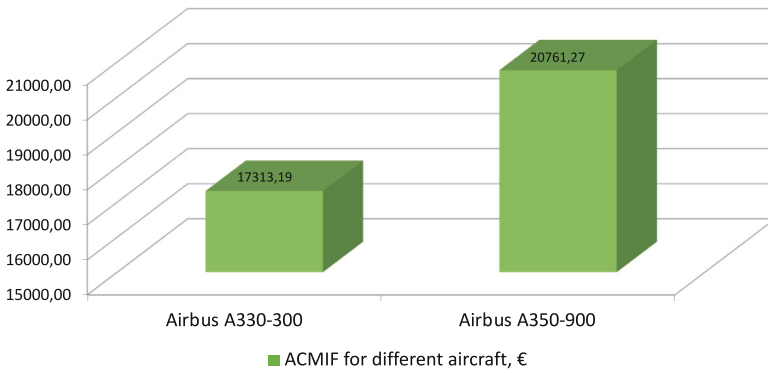


Fig. 7. ACMI of the Finnair Airline long-haul fleet.

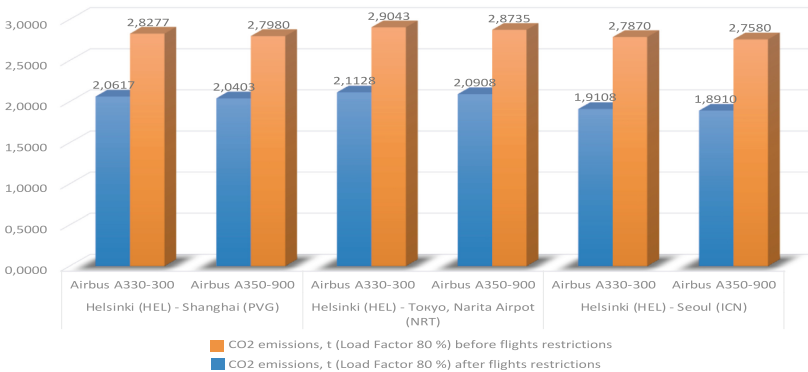


Fig. 8. CO2 emissions on the investigated routes during operation of different types of aircraft before and after flights restrictions: A Case of Finnair Airlines.

Average Lufthansa Airline operating costs on the selected routes between Europe and Asia have been increased by 18.62% after flights restrictions, while average CO₂ emissions on the investigated routes have been increased by 18.21% after the restrictions of flights (see Fig. 12, 13 and 14).

The conducted analysis showed that overflight of Ukrainian and Russian airspaces due to the military conflict contributes to a significant increase of airlines operating costs on the selected routes between Europe and Asia, varying from 38.6% to 18.62% and increase of CO₂ emissions varying from 40.15% to 18.21% depending on airlines. The performed research proved that Finnair Airlines is the most impacted airline by the Ukrainian conflict.

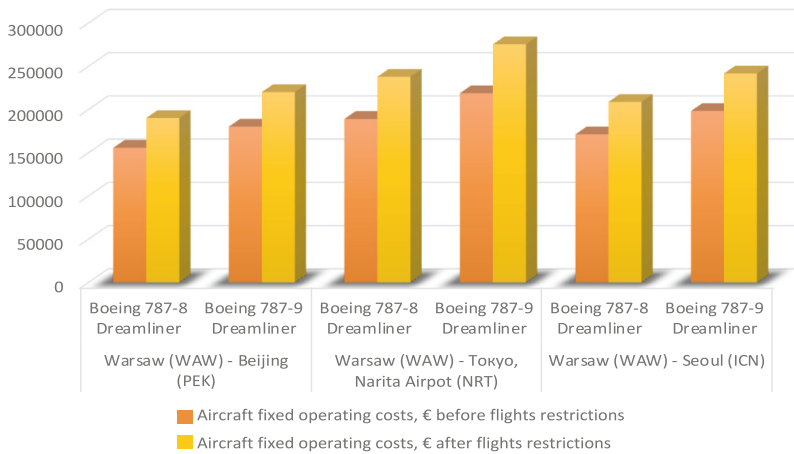


Fig. 9. Airline’s operating costs on the investigated routes before and after flights restrictions during operation of different types of aircraft: A Case of LOT Polish Airlines.

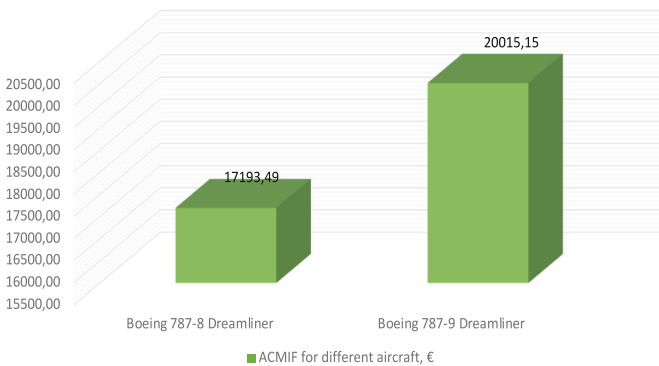


Fig. 10. ACMIF of the LOT Polish Airlines long-haul fleet.

At the final stage of the research, we developed a forecast of global aviation CO₂ emissions for the next 5 years under the two possible scenarios of military conflict development on the territory of Ukraine. Global aviation CO₂ emissions monthly statistics

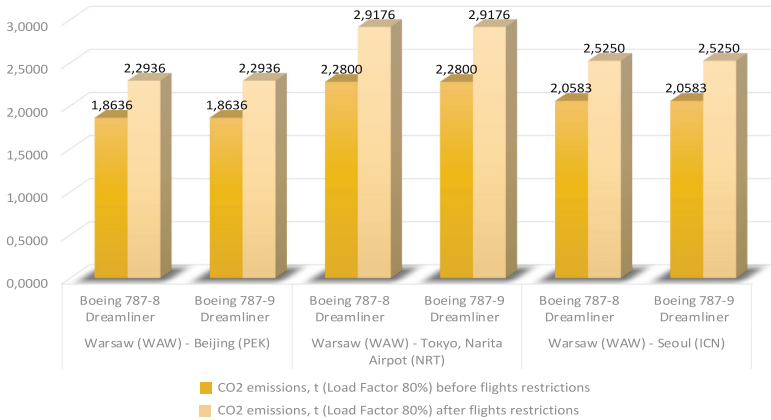


Fig. 11. CO2 emissions on the investigated routes during operation of different types of aircraft: A Case of LOT Polish Airlines.

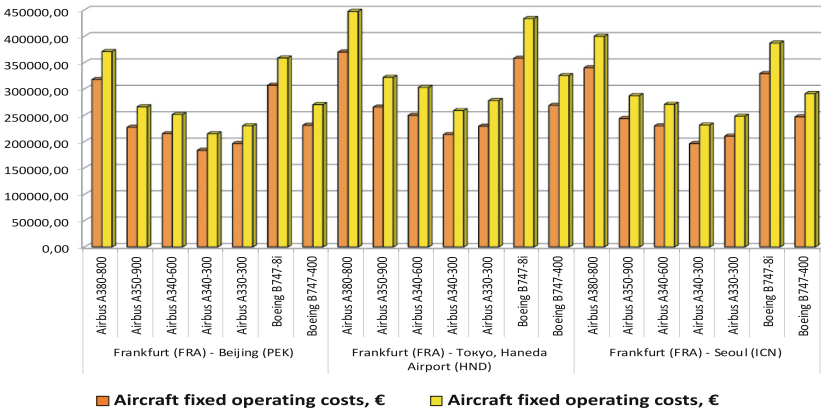


Fig. 12. Airline’s operating costs on the investigated routes before and after flights restrictions during operation of different types of aircraft: A Case of Lufthansa Airlines.

(in million metric tons) for 2020–2022 years (see Fig. 5) have been taken as an initial data for the forecasting model.

This initial data sample was transformed into logarithmic view to be applicable for the SARIMA model (see Fig. 12), then the ACF (autocorrelation function) and PACF (partial autocorrelation function) were analysed for the transformed data sample (see Fig. 13).

After this the logarithmic forecast with confidence intervals has been constructed, with the help of SARIMA model (see Fig. 14), which was coded in RStudio (see Fig. 15) (Figs. 17 and 18).

Main forecasting finding after the modelling were as follows:

- p-value of the model is 0.91 ($> = 0.85$), which confirms the sufficiently high accuracy of the forecast;

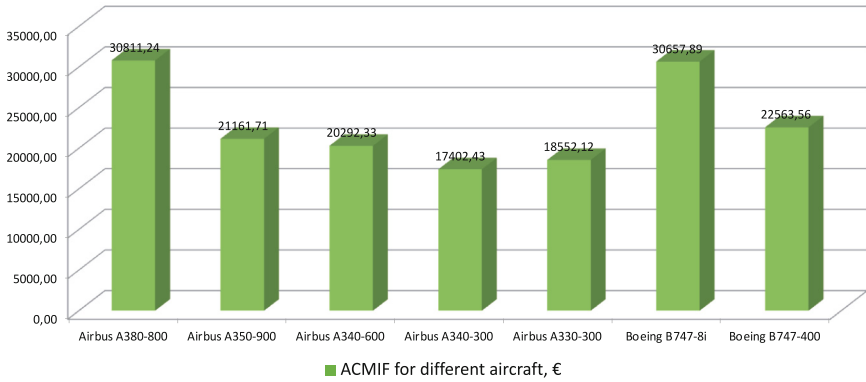


Fig. 13. ACMIF of the Lufthansa Airlines long-haul fleet.

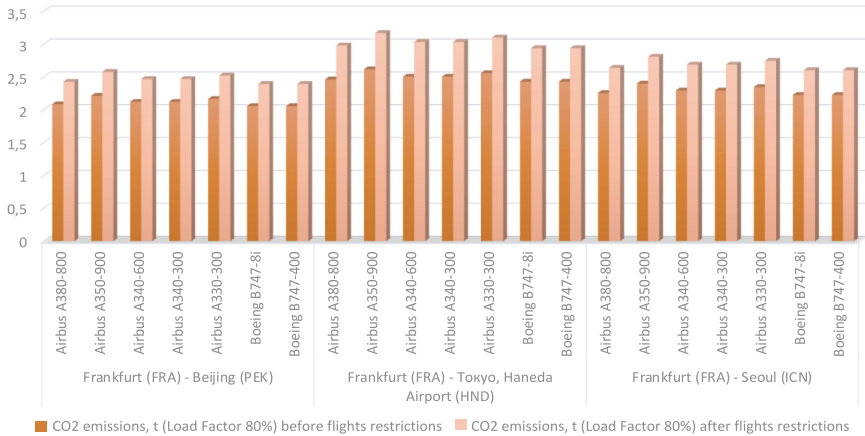


Fig. 14. CO2 emissions on the investigated routes during operation of different types of aircraft: A Case of Lufthansa Airline.

- global aviation CO₂ emissions in «realistic 2025 year» will reach ≈ 72 million metric tons per month (increased by 28.8% comparing with 2022), in «optimistic 2025 year» global aviation CO₂ emissions will reach ≈ 68 million metric tons per month (increased by 22.6%);
- by the end of 2023 the difference between two forecasts (optimistic and realistic) will be approximately 3% and by the end of 2025 it will be approximately 6 %.

The forecasted values of the global aviation CO₂ emissions for the next 5 years under two different scenarios of military conflict development of the territory of Ukraine determined with the help of SARIMA model in RStudio are presented on the Fig. 16 (Fig. 19).

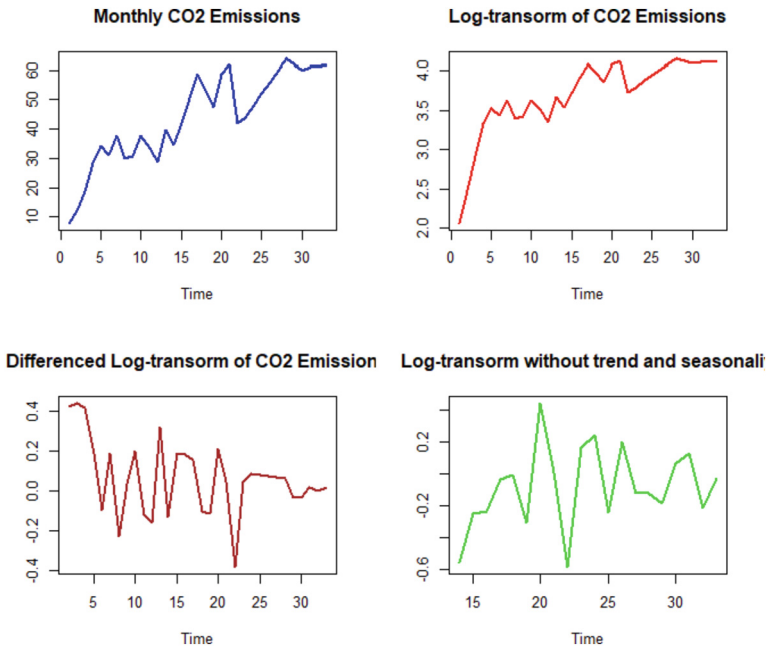


Fig. 15. Transformation of the global aviation CO₂ emissions monthly statistical data to be used in SARIMA model.

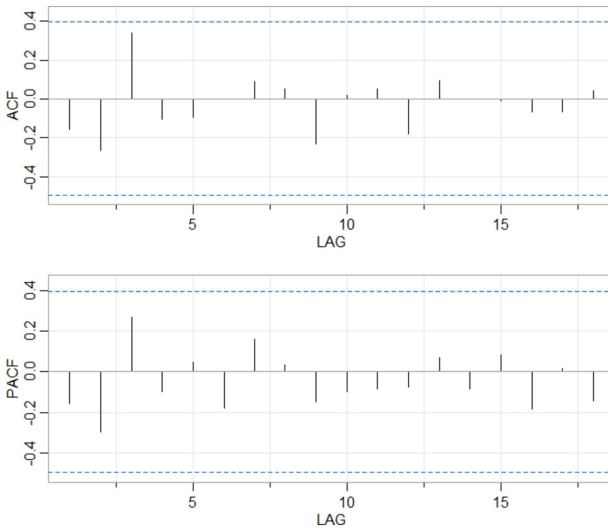


Fig. 16. Autocorrelation function (ACF) and partial autocorrelation function (PACF) of the transformed data sample.

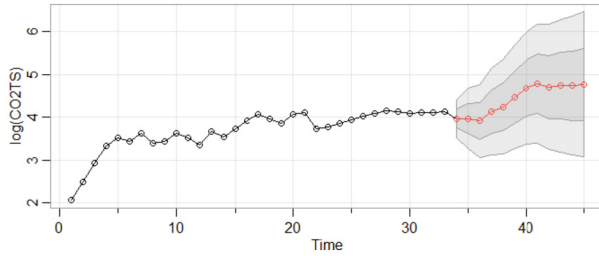


Fig. 17. SARIMA model and logarithmic forecast with confidence intervals.

```

7 CO2TS <- ts(CO2Data$CO2_Emissions)
8
9 par(mfrow=c(2,2))
10
11 plot(CO2TS, main='Monthly CO2 Emissions', ylab='', col='blue', lwd=2)
12 plot(log(CO2TS), main='Log-transform of CO2 Emissions', ylab='', col='red', lwd=2)
13 plot(diff(log(CO2TS)), main='Differenced Log-transform of CO2 Emissions', ylab='', col='brown', lwd=2)
14 plot(diff(diff(log(CO2TS)),12), main='Log-transform without trend and seasonality', ylab='', col='green', lwd=2)
15
16 data<-diff(diff(log(CO2TS)),12))
17 par(mfrow = c(2,1))
18 acf2(data, 18)
19
20 d=1
21 DD=1
22 per=12
23 for(p in 1:2){
24   for(q in 1:2){
25     for(i in 1:2){
26       for(j in 1:4){
27         if(p+d+q+i+DD+j<=10){
28           model<-arima(x=log(CO2TS), order = c((p-1),d,(q-1)), seasonal = list(order=c((i-1),DD,(j-1)), period=per))
29           pval<-Box.test(model$residuals, lag=log(length(model$residuals)))
30           sse<-sum(model$residuals^2)
31           cat(p-1,d,q-1,i-1,DD,j-1,per, 'AIC=', model$aic, ' SSE=',sse, ' p-VALUE=', pval$P.value,'\n')
32         }
33       }
34     }
35   }
36 }
37
38 CO2Model<- arima(x=log(CO2TS), order = c(1,1,1), seasonal = list(order=c(0,1,1), period=12))
39
40 plot(forecast(CO2Model))
41
42 forecast(model)
43
44 ac<-sarima.for(log(CO2TS),12,1,1,1,0,1,1,12)
45
46 plot.ts(c(CO2TS,exp(a$pred)), main='Monthly CO2 + Forecast', ylab='', col='blue', lwd=3)
47 exp(a$pred)

```

Fig. 18. Coded in RStudio SARIMA model.

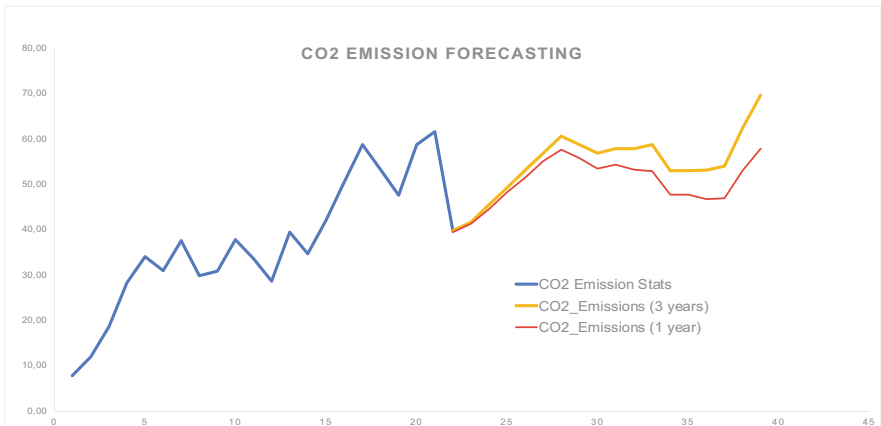


Fig. 19. Forecast of the global aviation CO₂ emissions for the next 5 years under two different scenarios of military conflict development of the territory of Ukraine.

5 Conclusions

This paper has investigated how war in Ukraine impacted global air transportation ecosystem on the example of three European airlines, i.e. Finnair, LOT Polish and Lufthansa Airlines, analysing their most popular direct routes between Europe and Asia before and after flight restrictions. The study considerably adds to the aviation industry research by investigating of the current and future state of the global air transportation ecosystem, impacted by the war in Ukraine. Result of the conducted research proves that Russia invasion of Ukraine led not only to the changes in air routes network between Europe and Asia, North America and Asia and North America and Middle East, but also significantly worsen the financial state of certain airlines and negatively affects environment. Performed analysis shows increasing of the airlines operating costs on the certain routes between Europe and Asia after flights restrictions from 38.6% to 18.62% and rising of CO₂ emissions from 40.15% to 18.21%, depending on airlines. Finnair Airlines seems to be the most impacted airline by the Ukrainian conflict.

This research also significantly contributes to the scientific approach for forecasting of the global aviation CO₂ emissions under the influence of war with the help of SARIMA model. Received data show that the overflight of Russian and Ukrainian air spaces due to the continuation of military conflict in Ukraine lead to the increasing of CO₂ emissions in “realistic 2025 year” (war will end within 3 years) on 28.8% and in “optimistic 2025 year” (war will end within one year) on 22.6% comparing with 2022, which can prevent the achievement of sustainable development goals in air transport within the established time frame.

Together with the airspace closures and flight restrictions, leading to the changing of air routes trajectories, increasing of airlines operating cost and CO₂ emissions, Russian invasion of Ukraine also affect slots at key airports worldwide. Many went unused, and others were affected by rescheduling and longer flight times. This is another topic, which needs further research.

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