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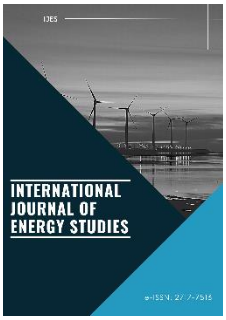

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A detailed emission analysis between regional jet and narrow-body passenger aircraft

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Highlights

- Comparison on the environmental impact of aircrafts
- Mapping fuel consumption and detailed total emissions
- Addressed the research gap in the selection of aircraft
- Promoting efficient and sustainable fleet selection for green airlines

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ABSTRACT

In this study, a comparison in terms of environmental impact is carried out between regional jet and narrow-body passenger aircraft with different Maximum Take-Off Weights (MTOW) and seating capacities considering the fuel burn and emissions. The flight trajectory is selected from Erzincan Yıldırım Akbulut Airport to Ankara Esenboğa Airport and that trajectory is a frequently performed domestic flight between Erzincan and Ankara. Integrated Aircraft Noise and Emissions Modelling Platform (IMPACT) developed by EUROCONTROL is used for the calculation of fuel burn, CO_2, H_2O, and other gas emissions (NO_x, SO_x, CO, HC, soot, and other trace compounds) for the per phase of flight. These emissions have an impact on human health, air quality, and the ecosystem, and cause air pollution, climate change, and global warming worldwide. Commercial air-transport-based simulations are created for regional jet and narrow-body passenger aircraft. According to the results, flying with regional jets which have lower MTOW from/to airports such as Erzincan Yıldırım Akbulut Airport, where the passenger density per aircraft is low, provides advantages in terms of fuel burn and emissions. It is expected that this study will serve as a guide for airline operators for fleet selection based on fuel burn and emission parameters.

Keywords: Aircraft emissions, $PM_{2.5}$, Fuel consumption, Regional jets, Narrow-body passenger aircraft

1. INTRODUCTION

1.1. Framework

Air traffic, air pollution, and greenhouse gas (GHG) emissions have increased in recent years because of air transport that has developed in parallel with technological developments. Aircraft emissions include 71.5% carbon dioxide (CO_2), 28% water vapor (H_2O), and 0.5% other gas emissions; nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), unburned or partially combusted hydrocarbons (HC), soot, and other trace compounds [1]. Some of these emissions release in proportion to the fuel burn (CO_2, H_2O, SO_x, and volatile organic compounds), while others vary nonlinearly with the fuel flow (NO_x, CO, and unburned hydrocarbons) [2]. While emissions which CO_2, H_2O, SO_x, and NO_x have a global warming effect, CO and HC emissions have more effect on Landing and Take-off (LTO) Cycle operations. Since landing and take-off activities are carried out near city centers, all exhaust emissions are released into living areas, and they directly affect human health, air quality, and the ecosystem [3], [4]. The air transport sector produces 14% of CO_2 emissions from the entire transport sector, but if no measures are taken, this value will increase to 22% by 2050 [5]. The annual report is based on measurements of fine particulate matter ($PM_{2.5}$) density per cubic meter, published by Switzerland-based air quality technology company IQAir. According to the report, air pollution, associated with over 6 million deaths annually, is seen as the biggest environmental health threat today. The report is based on the average annual $PM_{2.5}$ concentration ($\mu g/m^3$) across the countries and cities. According to the World Health Organization (WHO) standards, the $PM_{2.5}$ value must be at most 5 $\mu g/m^3$ to breathe clean air in a region. $PM_{2.5}$ concentration in Turkey is measured as 21.1 $\mu g/m^3$ on average in 2022. Results show Turkey became the 6th most polluted country among 43 countries in the European region. According to the report examining Turkey in the European region, Iğdır is the most polluted city in Europe [6]. In this study, the air traffic and aviation-based emissions for Erzincan City in Turkey are examined. It is observed that the passenger density per aircraft which operates from/to Erzincan Yıldırım Akbulut Airport is low. To select more suitable aircraft for aviation operations conducted at Erzincan, detailed fuel and emission analyses are carried out for regional jets which have lower Maximum Take-Off Weight (MTOW) and seat capacity and narrow-body passenger aircraft. According to the results of the analysis, the advantages of regional jet operations over narrow-body passenger aircraft operations conducted at airports such as Erzincan Yıldırım Akbulut Airport, where the passenger density per aircraft is low are presented in terms of environmental impact.

1.2. Previous Research

Although there are many studies on the environmental effects of aircraft in the world, in this study, the literature information about emission studies in Turkey is presented. Altuntaş and Karakoç presented a study regarding the environmental effects of domestic flights conducted between 2006 and 2009 in Eskişehir, Uşak, Adıyaman, Çanakkale, and Ağrı cities [3]. Ekici et al. calculated aircraft HC, CO, and NO_x emissions during the LTO for the busiest five airports in Turkey in 2012. Their emission findings are 215 tons/year, 1,483 tons/year, and, 1,417 tons/year for HC, CO, and NO_x respectively considering the related authority's databases [7]. Altuntaş calculated the global warming potential value (GWP) for aircraft in service across Turkish airports. The author carried out related calculations using the IPCC 2007 GWP 100a methodology. The study indicates that the average value of CO_2 e per passenger per airport is 12-13 kg and the average value of global warming potential per passenger per airport is 15.35 CO_2 e [8]. Yılmaz estimated aircraft gas emissions (NO_x, HC, and CO) during LTO cycles for Kayseri Airport using the flight data obtained from the State Airports Authority and the ICAO Engine Emission Data Bank (EEDB). According to the results, an increase of 25% in LTO cycles cause an increase in the emission rate of around 11% [9]. Kuzu presented aircraft emissions caused by LTO cycles at Atatürk International Airport. According to the research NO_x emission is calculated as 4249 tons, CO emission is calculated as 2153 tons, and HC emission is calculated as 181 tons for a year. Considering the results, while most of the CO and HC emissions are emitted during the taxi phase, most of the NO_x emissions are emitted during the climb phase [10]. Kumaş et al. calculated the carbon footprint from the data related to the flights conducted at Muğla airports in 2017. The Tier approach methodology is used for emission calculations. The CO_2 emission amount is determined as 93410,750 tCO_2 / year [11]. Özgünoğlu and Uygur performed an emission analysis for the LTO phase for the Kahramanmaraş airport using Tier 1 and 2 approaches. In addition, the SO_2 emissions emitted during the LTO phases are examined to determine the impact on the Kahramanmaraş Airport using MATLAB [12]. Ekici and Şöhret calculated the environmental and economic evaluation of aircraft-based emissions from flights conducted at Isparta airport in 2018. In the related study, real flight data are used to calculate environmental impact, environmental impact cost, and carbon footprint values [13]. Kafalı and Altuntaş presented NO_x, CO, and HC emissions caused by flights conducted at Dalaman Airport in Turkey considering the daily, number of flights and per passenger [14]. Yıldız et al. examined the possibilities of using renewable energy sources such as solar, wind, biomass, geothermal, and hydroelectricity to reduce energy costs and emissions at airports in Turkey [15]. Zeydan and Şekertekin determined the amounts of emissions caused by domestic flights conducted on 46 airports in Turkey using Tier 3A methodology. Results show that the total emissions are calculated as 1.67 million tons, 6472.23 tons, 2839.03 tons, and 80.52 tons for CO_2, NO_x, CO, and $PM_{2.5}$ respectively [16]. Dalkıran offered a scoring system for the use of sustainable materials in airports. The author has offered an alternative calculation to assess sustainable material use under the various airport operators in Turkey. According to the results, Istanbul Grand Airport (IGA) has the highest score among the studied airports [17].

2. MATERIAL AND METHODS

The two types of aircraft which are Turbofan 1 (narrow-body passenger aircraft), and Turbofan 2 (regional jet) are compared in terms of fuel consumption and emissions. Some information about the studied aircraft is presented in Table 1 [18]–[20].

Table 1. Some information about the studied aircraft

Aircraft Model	Turbofan 1	Turbofan 2
ICAO Wake Turbulence Category (WTC)	M	M
Approach Speed Categorization (APC)	C	C
Body Categorization	Narrow	Narrow
Service Ceiling (ft)	41,000	41,000
Maximum Range (nm)	3,500-3,750	2,500-2,750
Maximum Take-off Weight (MTOW)[tons]	65-75	45-55
Seat Configuration	175-185	115-135
Engine Count	2	2
Each Power Plant (kN)	115-120	85-105

In this study, Erzincan Yıldırım Akbulut Airport (ICAO code: LTCD, IATA code: ERC) is examined, while the latitude/longitude information of the airport is 39.710663 / 39.525137, and its elevation is 3,783 ft [21]. The relevant airport is one of the airports that use renewable energy sources. Erzincan Yıldırım Akbulut Airport is one of the airports that have a solar power plant in Turkey. For this purpose, 3,779 photovoltaic panels are used and an installed power of 2.09 MWp is reached. In this way, the airport can generate almost half of its electricity needs [15].

Flight phases consist of two main parts. The first part is called the LTO stage (taxi-out, take-off, climb-out, final approach, landing, and taxi-in), and the second part is called the CCD stage (climb, cruise, and descent) [22]. While aircraft-induced emissions at the CCD stage cause global air pollution, the LTO stage has a severe impact on local air quality [23]. If a greener airport is aimed, the flights conducted on the LTO stage which has more environmental effects below 3,000 ft should be considered [24], [25]. Erzincan Yıldırım Akbulut Airport includes domestic flights from/to Ankara Esenboğa Airport, İstanbul Sabiha Gökçen Airport, İstanbul Airport, and İzmir Adnan Menderes Airport organized by various airlines [26]. These flight points are given in Figure 1. According to the data collected from the State Airports Authority for the Erzincan Yıldırım Akbulut Airport, the total passenger number, and aircraft traffic for 2022 are given in Table 2 [27].

Figure 1. Flight points considering Erzincan Yıldırım Akbulut Airport

Table 2. Total passenger number and aircraft traffic for Erzincan Yıldırım Akbulut Airport

Month (2022)	Total Passenger Number for Domestic Flights (arrivals-departures)	Aircraft Traffic for Domestic Flights (arrivals-departures)	Average Passenger Number per Aircraft
January	15,327	122	125.6311
February	16,968	151	112.3709
March	17,214	153	112.5098
April	17,488	152	115.0526
May	27,634	211	130.9668
June	29,712	208	142.8462
July	31,575	219	144.1781
August	34,531	223	154.8475
September	24,581	195	126.0564
October	24,122	191	126.2932
November	23,176	182	127.3407
December	21,481	157	136.8217
Total	283,809	2,164	131.1502

Transportation is carried out with scheduled flights rather than charter flights which have a high seat occupancy rate per aircraft flying from/to the relevant airport. Narrow-body aircraft (Turbofan 1) with a capacity of 175-185 passengers are operated for the Erzincan Yıldırım Akbulut Airport [28]. As can be seen from Table 2, a total of 283,809 passengers carried out a flight, while a total of 2,164 aircraft traffic is observed from/to Erzincan Yıldırım Akbulut Airport in 2022. From the beginning to the end of 2022, there has been an increase in both the number of passengers and aircraft traffic in the summer months. The passenger number per aircraft varies monthly and stands out as 131.1502 on average. The average seat occupancy rate per aircraft has not reached the maximum seat configuration (175-185) which varies according to the airline operators. Therefore, in this study, the environmental effect of regional jets and narrow-body passenger aircraft, at airports with low passenger density per aircraft is examined.

Since the flights from Erzincan Yıldırım Akbulut Airport to Ankara Esenboğa Airport, İstanbul Sabiha Gökçen Airport, İstanbul Airport, and İzmir Adnan Menderes Airport vary according to the seasons and days [29] the flight conducted from Erzincan Yıldırım Akbulut Airport to Ankara Esenboğa Airport is considered and environmental effects are examined over this flight. The total distance of the flight is assumed to be 302.41 nm (560.063 km). The elevation of the airports is 3,783 ft for Erzincan and 3,125 ft for Ankara [21].

Eurocontrol's Impact

The IMPACT platform developed by EUROCONTROL includes the most recent Aircraft Noise and Performance Data (ANP), Advanced Emissions Model (AEM) which are based on the ICAO Aircraft Engine Emissions Database (AEED), and Base of Aircraft Data (BADA). The IMPACT platform uses the relative databases and the user inputs to calculate fuel burn, CO_2, H_2O, and other gas emissions (NO_x, SO_x, CO, unburned or partially combusted hydrocarbons, soot, and other trace compounds) as well as aircraft noise for each phase of flight. Definitions of the required emissions indices to calculate the pollutant amounts are shown in Table 3 [30].

Table 3. Non-engine specific indices

Species	Emission Index (EI)
kg CO_2 per kg fuel	3.16
kg H_2O per kg fuel	1.237
kg SO_x per kg fuel	0.00084

The IMPACT platform supports real-time and model-based simulation data and allows the theoretical selection of flight parameters. IMPACT currently generates seven out of nine flight segments. The 'taxi-out' and 'taxi-in' segments are not covered. The fuel burn and emission calculation for below 3,000 ft is based on the AEM database during the LTO stage. The fuel burn and emission calculation for above 3,000 ft is based on EUROCONTROL'S BADA during the CCD stage [30]. The IMPACT web-based modeling platform can be accessed via OneSky Online and an academic site license is defined for Erzincan Binali Yıldırım University by EUROCONTROL.

3. RESULTS AND DISCUSSION

The aircraft took off from Erzincan Yıldırım Akbulut Airport (ICAO code: LTCD, IATA code: ERC) which has an elevation of 3,783 feet, carried out a cruise phase at an altitude of 39,000 feet, and landed to Ankara Esenboğa Airport (ICAO code: LTAC, IATA code: ESB) which has an elevation of 3,125 feet, after a flight that continued for approximately 50 minutes. The IMPACT platform is used to model related trajectories to obtain results according to the related databases. Figure 2 illustrates a comparative fuel burn representation of Turbofan 1 and Turbofan 2 aircraft considering the flight phase for the selected trajectory.

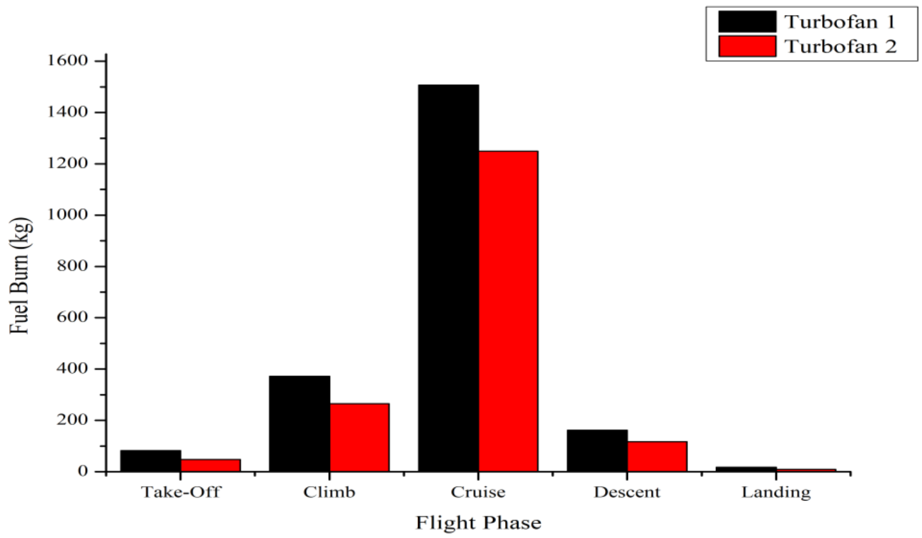

Figure 2. Turbofan 1 and Turbofan 2 fuel burn comparisons

The take-off phase has the highest fuel flow (137.2143 kg/min for Turbofan 1 and 94.5423 kg/min for Turbofan 2) as expected but the cruise phase has the highest fuel burn (1,507.13 kg for Turbofan 1 and 1,249.298 kg for Turbofan 2), while the landing phase has the lowest fuel burn (16.9088 kg for Turbofan 1 and 8.7963 kg for Turbofan 2) for both aircraft. The reason behind the fuel burn of the cruise phase is the distance taken throughout the relative phase (approx. 267 nm or 495 km). Turbofan aircraft are designed to operate at cruise altitudes where they are more efficient. The total fuel consumption of the Turbofan 1 and Turbofan 2 aircraft throughout all the flight phases are 2,140.709 kg and 1,686.889 kg, respectively (Considering Table 2 the annual domestic aircraft traffic-based total fuel burn difference is 982 tons). This can be explained by the aircraft's MTOW and passenger seat capacities. A detailed emissions map of each aircraft can be seen in Table 4 and Table 5 for Turbofan 1 and Turbofan 2 respectively.

Table 4. A detailed emissions map of the Turbofan 1

[kg]	Take-Off	Climb	Cruise	Descent	Landing	Total
NO_x	1.8923	8.5667	23.8834	1.486	0.1965	36.0249
CO_2	260.1583	1176.477	4762.531	512.0442	53.4318	6764.642
SO_x	0.0691	0.3127	1.2659	0.1361	0.0142	1.798
H_2O	101.8405	460.5386	1864.32	200.4426	20.9162	2648.058
CO	0.0434	0.2098	5.5703	1.0883	0.0347	6.9465
HC	0.0086	0.0419	0.6476	0.099	0.0024	0.7995
formaldehyde	0.0012	0.006	0.0926	0.0141	0.0003	0.1142
PM_{total}	0.0098	0.0477	0.2406	0.0101	0.0012	0.3094
PM_{sul}	0.0042	0.0205	0.1201	0.0085	0.0008	0.1541
$PM_{2.5}$	0.0098	0.0477	0.2406	0.0101	0.0012	0.3094
$PM_{0.1}$	0.0098	0.0477	0.2406	0.0101	0.0012	0.3094
Total	364.047	1646.316	6659.153	715.3491	74.6005	9459.466

Table 5. A detailed emissions map of the Turbofan 2

[kg]	Take-Off	Climb	Cruise	Descent	Landing	Total
NO_x	0.8666	4.1593	14.1506	0.7759	0.0755	20.0279
CO_2	149.3769	837.0209	3947.781	368.5955	27.7964	5330.571
SO_x	0.0397	0.2224	1.0494	0.0979	0.0073	1.4167
H_2O	58.4744	327.6566	1545.381	144.2888	10.881	2086.682
CO	0.0413	0.2484	4.1772	2.0716	0.0468	6.5853
HC	0.0034	0.0209	0.2393	0.1694	0.0024	0.4354
formaldehyde	0.0004	0.0029	0.0342	0.0242	0.0003	0.062
PM_{total}	0.0049	0.0286	0.1702	0.0082	0.0005	0.2124
PM_{sul}	0.0024	0.0146	0.1001	0.0061	0.0004	0.1236
$PM_{2.5}$	0.0049	0.0286	0.1702	0.0082	0.0005	0.2124
$PM_{0.1}$	0.0049	0.0286	0.1702	0.0082	0.0005	0.2124
Total	208.8198	1169.432	5513.423	516.054	38.8116	7446.541

A total of eleven types of emissions (NO_x, CO_2, SO_X, H_2O, CO, HC, formaldehyde, PM_{total}, PM_{sul}, $PM_{2.5}$, $PM_{0.1}$) are evaluated. The total CO_2, H_2O, and SO_x emissions, which are the product of the complete combustion of kerosene, and proportional to the fuel burn induced by Turbofan 1 and Turbofan 2, are 9,414.498 kg and 7,418.67 kg, respectively (Considering Table 2 the annual domestic aircraft traffic-based total CO_2, H_2O, and SO_x emissions difference is 4.3189 k tons). The total NO_x emissions, which are non-linear parameters of the fuel flow and the engine throttle induced by Turbofan 1 and Turbofan 2, are 36.0249 kg and 20.0279 kg, respectively (Considering Table 2 the annual domestic aircraft traffic-based total NO_x emissions difference is 34.6175 tons). The total CO and HC emissions, which are the result of incomplete combustion of kerosene induced by Turbofan 1 and Turbofan 2, are 7.746 kg and 7.0207 kg, respectively (Considering Table 2 the annual domestic aircraft traffic-based total CO and HC emissions difference is 1.5695 tons). The total $PM_{2.5}$ emissions induced by Turbofan 1 and Turbofan 2, are 0.3094 kg and 0.2124 kg, respectively (Considering Table 2 the annual domestic aircraft traffic-based total $PM_{2.5}$ emissions difference is 0.2099 tons). The total emissions induced by Turbofan 1 and Turbofan 2, are 9,459.466 kg (LTO: 438.6475 kg, CCD: 9,020.8185 kg) and 7,446.541 kg (LTO: 247.6314 kg, CCD: 7,198.9096 kg), respectively (Considering Table 2 the annual domestic aircraft traffic-based total emission difference is 4.3559 k tons).

4. CONCLUSION

The World Health Organization (WHO) declared standards for the $PM_{2.5}$ and this emission parameter must be at most 5 $\mu g/m^3$, but only 13 out of 131 countries can meet this standard according to the recent IQAir report. In today's world, where global warming has gained importance and environmental awareness has increased, the importance of environmental effects has increased in aviation. The air transport sector has the fastest growth among the emissions sources that have caused global warming and climate change in recent years. These emissions have an impact on human health, air quality, and the ecosystem, and cause air pollution, climate change, and global warming worldwide. Short-haul flights occur relatively mostly on the ground and at low altitudes and affect air quality near the airport. In this study, the environmental effect of regional jets and narrow-body passenger aircraft is examined for a domestic short-haul flight. The air traffic and aviation-based emissions for Erzincan City in Turkey are examined. As can be seen from the results, regional jet burns less fuel (the annual difference is 982 tons) and emits less emissions (the annual difference is 4.3559 k tons) than narrow-body passenger aircraft both at the LTO stage which has a severe impact on local air quality and CCD stage which causes global air pollution. Instead of narrow-body passenger aircraft added to their fleets by airline operators for use both in regional and international flights, regional jets should be preferred for use in regional flights from/to airports with low passenger density per aircraft. By this way, the fuel burned, and the emissions emitted to nature can be reduced for the same trajectory. The Turkish civil aviation authority needs to conduct a vision study to re-examine existing aircraft in environmental terms and should enforce emissions restrictions. In this way, airline operators will also consider noise and emission parameters besides operating costs, aircraft price, ease of maintenance, operational flexibility, and comfort in fleet selection.

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DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ugur Kilic: Performed all the calculations, design all the materials, and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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