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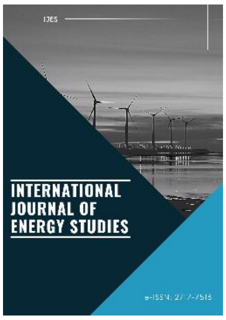

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Travel option-based environmental comparison between passenger aircraft and high-speed rail

Ugur Kilic[a*], Omer Cam[b]

[a] *Department of Avionics, Ali Cavit Celebioglu Civil Aviation College, Erzincan Binali Yıldırım University, Erzincan, 24100, Turkey, ORCID: 0000-0002-1576-8042*

[b] *Department of Aircraft Maintenance and Repair, Ali Cavit Celebioglu Civil Aviation College, Erzincan Binali Yildirim University, Erzincan, 24100, Turkey, ORCID: 0000-0003-4391-5609*

*(*Corresponding Author: ugur.kilic@erzincan.edu.tr)*

Highlights

- Reducing greenhouse gas emissions by changing travel options.
- Calculating emissions for an aircraft and high-speed train.
- Promoting efficient and sustainable fleet selection for green airlines.

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ABSTRACT

The short-haul flights have higher emission values than medium or long-haul flights when emissions per distance are considered. In this study, the potential to reduce greenhouse gas emissions by replacing short-haul flights which carried out by a narrow-body commercial aircraft from/to Konya City in Turkey with regional jets or high-speed trains (HSRs) has been investigated. The flight trajectory is selected from Konya Airport to İstanbul Sabiha Gökçen Airport, and that trajectory is a frequently performed domestic flight between Konya and İstanbul. The IMPACT platform is used for the calculation of fuel burn and gas emissions. According to the results, traveling with regional jets or high-speed trains from/to Konya City which is the most 15th polluted city in Europe, provides advantages in terms of environmental impact. Traveling with HSR which is the best traveling option in this study, provides approximately 3.3 times more green travel than the currently used narrow-body passenger aircraft between Konya and İstanbul. In addition, this mode of transportation can become more environmentally friendly by using renewable energy sources to produce its electricity needs. It is expected that this study will serve as a guide for airline and high-speed rail operators and regulators to determine the most environmentally efficient travel options based on fuel burn and emission parameters.

Keywords: Emissions, CO_2, $PM_{2.5}$, Travel options, Aircrafts, High-speed trains

1. INTRODUCTION

1.1. Framework

Human beings inevitably need the energy to maintain their daily life. Post World War II, factors such as industrialization and urbanization have increased the demand for natural energy resources because of the uncontrolled global population increase [1]. The need for energy continues to increase day by day. Based on Vaclav's historical estimates of primary energy consumption [2] and updated values from BP's Statistical World Energy Review, global energy consumption has increased from 28,564 TWh (terawatt-hours) in 1950 to 176.431 TWh in 2021 [3]. Parallel to this increase, CO_2 emissions released to nature have also increased [4]. Despite the increase in investments in clean and renewable energy sources, a large part of the energy needed today (about 85.5%) is still met from fossil fuels (natural gas, oil, and coal) [5]. The increase in the use of fossil fuels has revealed many environmental problems such as pollution, global warming, greenhouse gas, and climate change [6-8]. Visible environmental effects have begun to emerge as a result of the deterioration of the balance between the release of CO_2 (in other words, the release of carbon-containing energy sources in the form of solid - coal, coke, anthracite, long-lasting ovals, charcoal, peat, etc.-, liquid -oil, diesel, gasoline, kerosene, etc.-, or gas -natural gas, liquefied petroleum gas, shale gas, etc.- as a result of the combustion reaction) and the conversion of this released CO_2 back into an energy form. After the negative effects of environmental problems on living life were noticed, environmental awareness began to emerge all over the world. To increase countries' and societies' awareness of handling with negative effects of the environment, many international conferences, symposiums, etc. were held, and the most important of which was the Kyoto Protocol signed in 1997 [9]. Within the scope of this protocol, it is aimed to reduce the emission of carbon dioxide and greenhouse gases. The Paris Agreement which is one of the recent studies to reduce emissions is signed in 2015 within the scope of the United Nations Framework Convention on Climate Change [10]. Under this agreement, the long-term temperature target aims to limit the worldwide average temperature increase to 2°C from pre-industrial levels, and even reduce it to levels by one and a half degrees [11, 12]. According to the World Resources Institute and Climate Watch publication, which includes global greenhouse gas emissions by sector, the transportation sector, with 15.9%, constitutes the second highest source of greenhouse gas emissions after electricity and heating (30.4%) [13]. In the transportation sector, road transportation is 11.9% responsible for greenhouse gas emissions, while air is %1.9 and the remaining amount is released from rail, ship, and other transportation types. One of the main reasons for the high share of fossil fuels results from flights that are not well resolved in the air transportation sector [13]. In the report investigating the effect of the global economic crisis on airframe use by EUROCONTROL, CND (Cooperative Network Design) / CODA (Central Office for Delay Analysis), short-haul flights were defined as flights with routes shorter than 1500 km (approximately 810 nm) [14]. Moreover, according to the classification carried out based on seven different route ranges (long-haul flights, medium-haul flights, short-haul flights, mixed long-haul/medium-haul, mixed medium-haul/short-haul, mixed long-haul/short-haul, and mixed long-haul/medium-haul/short-haul), 89.5% of the flights in the world consist of short-haul flights [14]. In addition to having a high share in short-haul flights, it has also higher emission values than medium or long-haul flights when emissions per distance are considered [15] (Differences or exceptions may be observed in the results when considering loading conditions or other factors).

1.2. Previous Research

The extant literature has many studies aiming to reduce carbon emissions and employing different methods by comparing different transportation modes. For instance, in one of these studies, Baumeister explored the potential to reduce greenhouse gas emissions by replacing short-haul flights within Finland with car travel, train, and bus, considering actual travel times. The results show that using land-based transportation modes can significantly reduce Finland's climate impact compared to short-haul flights, and present land-based modes of transport can catch aircraft travel times on routes up to 400 km [15]. Givoni and Rietveld investigated the comparison of the environmental impact of operating wide or narrow-body aircraft on short-haul routes. Environmental impact analysis of wide and narrow body aircraft was carried out at three different distances on Sapporo–Tokyo (CTS–HND), Los Angeles–Chicago (LAX–ORD), and Barcelona–Madrid (BCN–MAD) routes. The study implies that changing the airframe from narrow-body to wide-body, in other words, increasing the number of seats would be more efficient than the flights on the examined routes, when the environmental impact is considered in detail (in terms of local air pollution (LAP), fuel consumption, emissions, costs for LAP and climate change, noise levels, etc.). In addition, in terms of noise pollution, it has been determined that the fleet nose exposure values are lower in the use of wide-body aircraft than in narrow-body aircraft. Finally, air traffic will decrease due to the relatively high number of passengers carried per flight in the use of wide-body aircraft. This situation seems to be an important factor to be considered in airports where finding the slot is difficult and costly [16]. Miyoshi and Mason have developed a detailed carbon calculator prototype for three air transport markets. Considering the three markets -the North Atlantic routes, intra-EU routes serving the UK, and the UK domestic routes- a sophisticated carbon calculator was developed that uses real flight data by airlines (the data were obtained by respecting the cabin configurations, flight cruising altitude and passenger load conditions on the routes where the study was carried out). The results showed that differences in airline strategies, such as the type of aircraft used, load factors, and seat configurations, also cause differences in carbon emission levels. In addition, it was emphasized that it is important to share carbon emission data by the airline in sales points or networks so passengers to choose the most efficient airline, thus guiding airlines to seek ways to reduce carbon emissions per passenger [17]. Morrell (1) examined the relationship between fuel/emission efficiency and aircraft size or capacity with passengers and cargo loaded, (2) evaluated past trends in capacity for short/medium/long-haul operations, and (3) assessed future emission predictions by evaluating the size of aircraft. As a result, it has been found that fuel efficiency is related to aircraft size, and trading with short/medium-haul aircraft is more beneficial than long-haul aircraft. In addition, it was stated that airlines started to implement intermediate stops on very long flights due to the ongoing high fuel prices, but this situation was not considered in the long-term strategies of aircraft manufacturers [18]. Filippone and Parkes examined the network of commuter flights with less than 300 nm distance for Europe and identified alternative connections at 100-150 nm flight distances. An analysis has been carried out on the use of turboprop aircraft and its impact on the environment among the defined alternative flights. The emission levels of CO, SO_x, CO_2, UHC, NO_x, and non-volatile particulate matter were presented and analyzed as a function of distance, altitude, and city pairs. As a result of the study, several domestic routes with a range of less than 200 nm were identified in the United Kingdom, France, Poland, and Germany, and it was shown that they included a significant number of commuter flights over flat terrain. In some cases, exhaust emissions were found to be released at stratospheric altitudes. It has been stated that emissions can be significantly reduced with a detailed examination of the frequencies of the routes, and it would be beneficial for airlines and aviation authorities to review the routes [19]. Tosun has compared the types of transportation operating between the existing high-speed train lines in Turkey and the effects of high-speed trains such as travel time, safety, transportation costs, and comfort have been examined. It is stated that in cases where the travel time by rail is less than 2 hours, high-speed trains completely dominate the market, and airline companies give up competing; when the travel time of the railway is between 3.5 and 5 hours, air transportation is the dominant mode of transportation compared to the rail. The author also emphasized that this traffic split can be affected by other parameters such as the locations of stations and airports, ticket prices, and service frequency. Because the gas emission values of highways and airlines are higher than high-speed trains in terms of environmental sensitivity, it has been concluded that high-speed trains are preferred in intercity transportation and that other types use foreign-dependent and non-renewable energy sources, as well as the use of renewable energy sources by high-speed trains overlaps with the concept of sustainable transportation [20].

1.3. The Motivation, Aim, and Contributions of the Study

Based on the annual report published by the Swiss-based air quality technology company for 2022, the following results were obtained according to the fine particulate matter ($PM_{2.5}$) density measurements per cubic meter published by IQAir. According to the World Health Organization standards, in data based on the average annual $PM_{2.5}$ concentration (µg/m^3) across countries and cities, the $PM_{2.5}$ value must be at most 5 µg/m^3 for a region to breathe clean air. The data, with $PM_{2.5}$ concentration measured as 21.1 µg/m^3 on average in 2022, show that Turkey is the 6th most polluted country among 43 countries in the European region. According to the report examining Turkey in the European region, Konya is the most 15th polluted city in Europe with a 34.5 µg/m^3 $PM_{2.5}$ value [21]. In this context, the present study was conducted to reduce travel-based carbon emissions related to Konya City. Air transportation is preferred in conditions where travel time is important, but how it can be done most environmentally is examined in this study, and it is evaluated that the HSR can be preferred for more environmentally beneficial travel in conditions where travel time is not so important for the passenger. Accordingly, in the study, airways and railways-based emissions for Konya City in Turkey are examined and compared. It has been determined that the number of passengers per aircraft in flights from/to Konya Airport is low. To decide on more efficient and environmentally friendly aircraft selection for airline operations from/to Konya, detailed fuel and emission analyzes are carried out for regional jets 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 Konya Airport are presented in terms of environmental impact. In addition, the results are presented by comparing the environmental impact of using aircraft or high-speed trains on the same route. The study implies that railways which are alternatives to the airways can be encouraged between Konya and İstanbul.

2. MATERIAL AND METHODS

2.1. Study Material

Fuel consumption and emissions of the two types of aircraft which are Turbofan 1 (narrow-body passenger aircraft), and Turbofan 2 (regional jet) are compared in detail. Table 1 shows some information about the aircraft used as alternatives in the study [22-24]

Table 1. Information related to the studied aircraft

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

In this study, Konya Airport (ICAO code: LTAN, IATA code: KYA) is examined, while the latitude/longitude information of the airport is 37.979 / 32.561847, and its elevation is 3,381 ft [25]. Konya Airport includes domestic flights from/to, 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 (DHMİ) for the Konya Airport, the total passenger number, aircraft traffic, and average passenger number per aircraft for 2022 are given in Figure 2 [27].

Figure 1. Flight points considering Konya Airport [26]

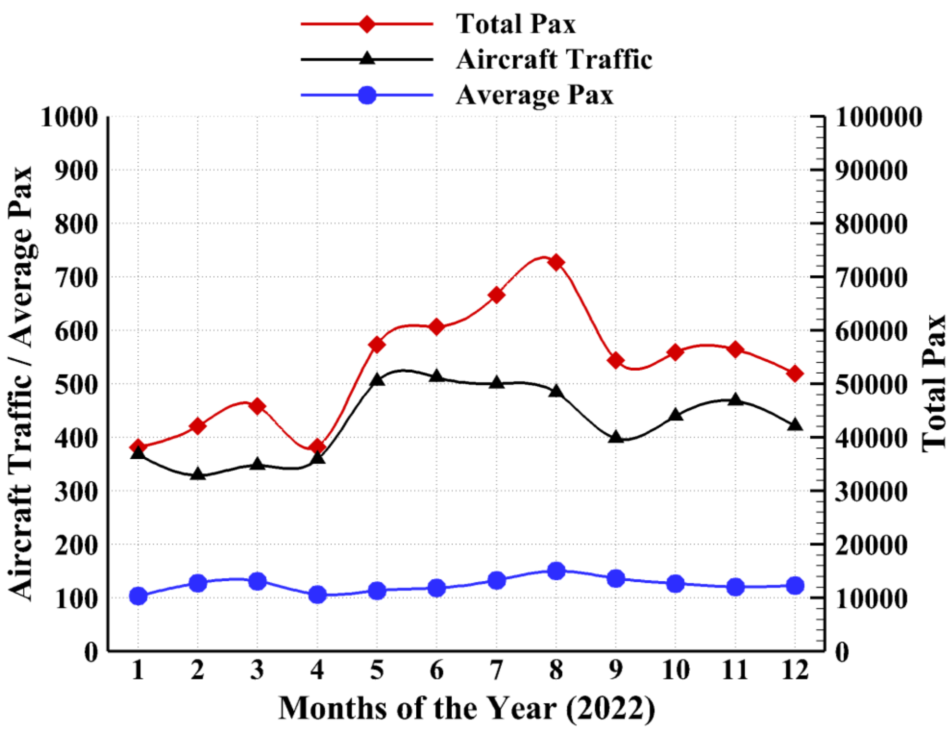

Figure 2. Total pax, aircraft traffic, and average pax for Konya Airport [27]

Narrow-body aircraft (Turbofan 1) with a capacity of 175-185 passengers is operated for Konya Airport [28]. As can be seen from Figure 2, a total of 640,557 passengers carried out a flight, while a total of 5,132 aircraft traffic is observed from/to Konya Airport in 2022. The passenger number per aircraft varies monthly and stands out as 124.8163 on average. The average seat load factor did not reach the maximum seat configurations (175-185), which vary according to airline operators. Therefore, in this study, the environmental impact of preferring regional jets instead of narrow-body aircraft at airports with low passenger density is investigated. Since the flights from Konya Airport to İstanbul Sabiha Gökçen Airport, İstanbul Airport, and İzmir Adnan Menderes Airport vary in accordance to the seasons and days [29], the flight operated from Konya Airport to İstanbul Sabiha Gökçen Airport is considered as a case in this study and environmental effects are examined over this flight (since it is the closest airport where the flight takes place). The total distance of the flight is assumed to be 231.2472 nm (428.2698 km). The elevation of the airports is 3,381 ft for Konya Airport and 312 ft for İstanbul Sabiha Gökçen Airport [25]

The high-speed trains, which greatly facilitate our lives in intercity transportation, connect different cities, passengers, and cultures. The high-speed trains used in Turkey are the HT65000 model, which is manufactured by Siemens in Spain. Some information about the HSR vehicle is presented in Table 2 [30, 31].

Table 2. Some information about the HSR vehicle

Route	Konya-İstanbul (Söğütlüçeşme)
HSR Model	HT65000
Maximum Output Power	4,800 kW
Maximum Speed	250 km / h
Length of String	158.92 m
Number of Passengers	419
Electric Systems	25 kV 50 Hz AC
Energy Consumption	4,000 kWh
Route Length	363.39 nm (673 km)
Route Duration	4 hours 40 minutes
Energy Consumption Per Trip	18,640 kWh

TCDD which is an official railway operator in Turkey is a member of the International Railways Association (UIC). Therefore, the railway systems used in Turkey are fully compatible with the latest technology systems used in Europe such as ERTMS (European Railway Train Operating System) and ETCS-Level 1 (European Train Control System-Level 1). A total of 5 round HSR trips are carried out every day between the Konya-İstanbul high-speed train route, which will be examined within the scope of this study. Turkey's high-speed railway network is given in Figure 3 [30, 31].

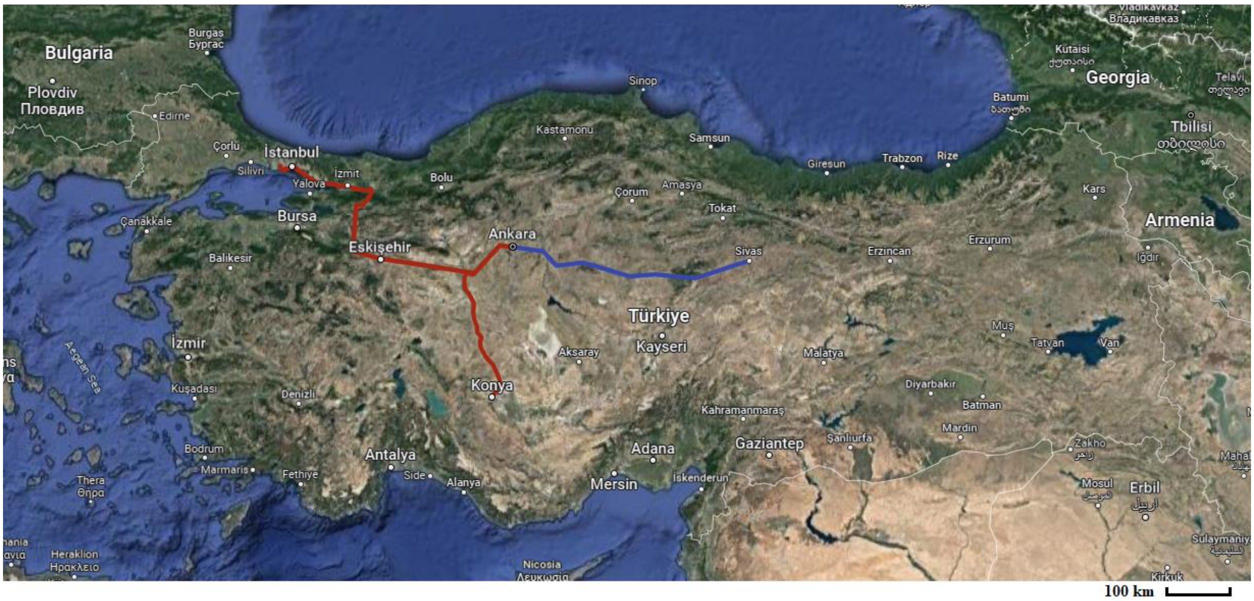

Figure 3. Turkey's high-speed railway network [30]

Fossil and electricity resources are widely used in the transportation sector. Since the fossil resources used in the production of electrical energy are less, the amount of emissions released to nature will be significantly less in the transportation sector where electrical machines are used. This situation varies according to the renewable energy infrastructures of the countries. While the technologies used to transform the energy in natural resources such as water, wind, and sun into usable energy forms in modern life diversify and develop, the use of wastes reaching thousands of tons in energy production is also increasing. Biomas, which is a sustainable and renewable resource, stands out as a type of energy obtained by burning organic materials. Electricity can be produced from biomass and waste heat in almost all regions of Turkey. While Turkey's biomass and waste heat energy reaches a capacity of 2,380 megawatts with power plants located in 74 provinces, Konya which is the investigated province in this study ranks 7th with 81.6 percent in biomass electricity generation [32]. Turkey Electricity Production and Electricity Consumption Point Emission Factors represent the amount of greenhouse gas emissions released per unit of net electricity production and unit of electricity consumption. These factors can be used in various fields such as calculations of carbon footprint and greenhouse gas reduction amounts provided by improvements in energy efficiency. According to the calculations, an average of 0.440 tons of CO_2 equivalent greenhouse gas emissions per 1 MWh (unit) net electricity generation is released in Turkey. Although the emission factors of the electricity consumption point vary in line with the connection point, 0.447 tons of CO_2 equivalent greenhouse gas emissions are released per unit of electricity consumption for the consumption point connected to the transmission line, and 0.484

tons of CO_2 equivalent greenhouse gas emissions are released per unit electricity consumption for the consumption point connected to the distribution line [32].

2.2. 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 relevant databases and user input to calculate fuel consumption, H_2O, CO_2, and other gaseous emissions (SO_x, NO_x, CO, unburned or partially burned hydrocarbons, soot, and other trace compounds), as well as aircraft noise for each flight stage. The appearance of the IMPACT web-based modeling platform is given in Figure 4 [33].

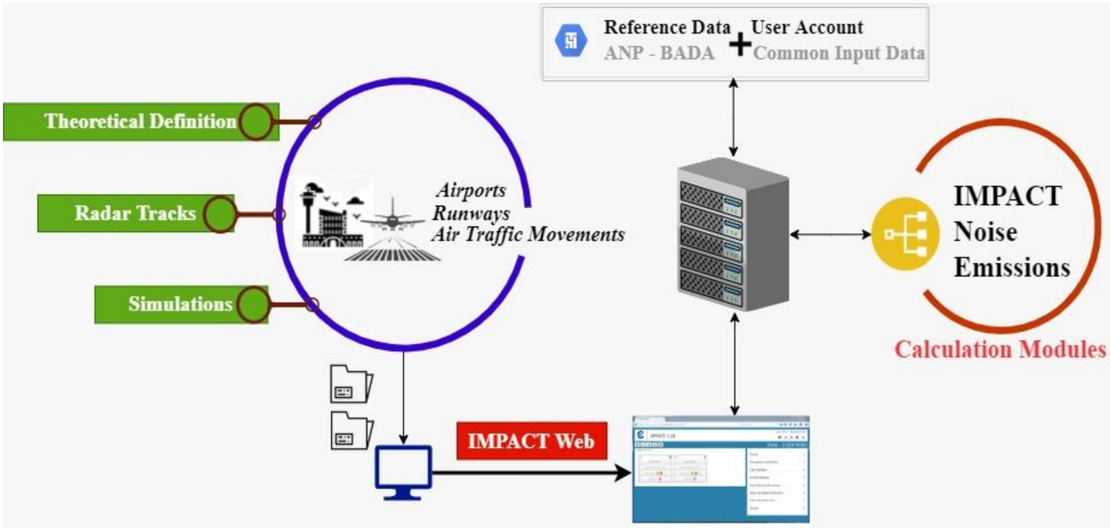

Figure 4. IMPACT web-based platform [33]

Access to the IMPACT web-based modeling platform is provided via OneSky Online, and an academic site license has been defined for Erzincan Binali Yıldırım University by EUROCONTROL. The definitions of the emission indices required to calculate the pollutant amounts are shown in Table 3 [33].

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

2.3. Kerosene Combustion

Kerosene is a liquid fuel at room temperature consisting of different hydrocarbon mixtures with a carbon content of about 9 to 15, which varies depending on the content of the raw material and the distillation process applied in the refinery. Kerosene-type jet fuels are generally non-volatile, and the main components are alkanes (n-octane, n-decane, n-dodecane, n-tetradecane, n-hexadecane, isooctane, isocetane, etc. up to 50% by volume), cycloalkanes (methylcyclohexane, decalin, etc. up to 35% by volume) and aromatics (toluene, xylene, butyl-benzene, n-propylbenzene, etc. up to 25% by volume). It is mixed with different additives with low concentrations to increase fuel stability and regulate the working conditions as desired [34]. Although the chemical formulations used for the combustion reaction of kerosene differ in the literature (C_{10}-C_{12}), the chemical formulation of $C_{12}H_{23}$ is generally preferred [35]. Table 4 shows the approximate chemical formulations of typical aviation fuels [36], their stoichiometric combustion equations, and the amount of CO_2 released per kg of fuel.

Table 4. Typical aviation fuels and combustion properties

Fuel	Formula (Approximate)	Stoichiometric Combustion Equation with Air	Released CO_2 per kg of fuel
JP-4	$C_{8.5}H_{17}$	$C_{8.5}H_{17} + 12.75(O_2 + 3.76N_2) \rightarrow 8.5CO_2 + 8.5H_2O + 47.94N_2$	3.142857 kg
JP-5	$C_{12}H_{22}$	$C_{12}H_{22} + 17.5(O_2 + 3.76N_2) \rightarrow 12CO_2 + 11H_2O + 65.8N_2$	3.180722 kg
JP-7	$C_{12}H_{25}$	$C_{12}H_{25} + 18.25(O_2 + 3.76N_2) \rightarrow 12CO_2 + 12.5H_2O + 68.62N_2$	3.124260 kg
JP-8	$C_{11}H_{21}$	$C_{11}H_{21} + 16.25(O_2 + 3.76N_2) \rightarrow 11CO_2 + 10.5H_2O + 61.1N_2$	3.163398 kg

Stoichiometric combustion assumes that the ideal fuel and air mixture and all reactants complete their reactions. Neither the fuel and the air are pure, nor are all the combustion reaction steps complete. So, CO, CO_2, SO_2, NO_x, N_2O, volatile organic compounds, unburned HC, etc. released into nature. It provides some evidence that significant amounts of these fine particles from kerosene combustion can impair lung function and increase the risks of infectious diseases (including tuberculosis), asthma, and cancer [37].

2.4. Study's Limitations

Taxiing, pre-flight vehicles, ground support equipment and land vehicles, and power and heat generation units are among the sources of gas emission and are harmful to the environment, however, these sources are not included in the study.

3. RESULTS AND DISCUSSION

The aircraft took off from Konya Airport (ICAO code: LTAN, IATA code: KYA) which has an elevation of 3,381 feet, carried out a cruise phase at an altitude of 33,000 feet, and landed to İstanbul Sabiha Gökçen Airport (ICAO code: LTFJ, IATA code: SAW) which has an elevation of 312 feet, after a flight that continued for approximately 40 minutes. The IMPACT platform is used to model the relevant trajectories to get the result according to the relevant databases. Figure 5 shows a comparative fuel burn representation of Turbofan 1 and Turbofan 2 aircraft, considering the flight stage for the selected trajectory.

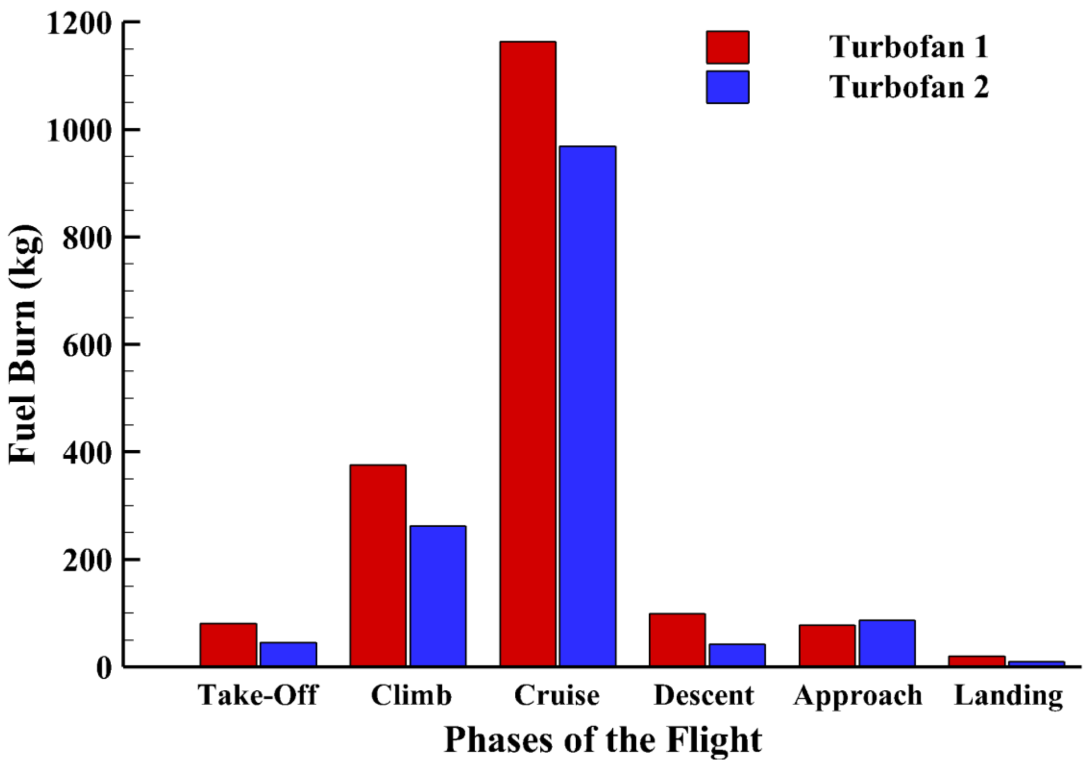

Figure 5. Turbofan 1 and Turbofan 2 fuel burn comparisons

The take-off phase has the highest fuel flow (138.6413 kg/min for Turbofan 1 and 95.0692 kg/min for Turbofan 2) as expected however, the cruise phase has the highest fuel burn (1,163.7013 kg for Turbofan 1 and 968.9499 kg for Turbofan 2), while the landing phase has the lowest fuel burn (19.9877 kg for Turbofan 1 and 10.2928 kg for Turbofan 2) for both aircraft. The reason for the fuel burning during the cruise phase is the distance traveled (about 195 nm or 361 km) during the respective phase. The total fuel consumption of Turbofan 1 and Turbofan 2 aircraft in all flight phases is 1,817,93 kg and 1,417,8891 kg, respectively (Total fuel burning difference based on annual domestic air traffic is 2,053 k tons).

A total of eleven types of emissions (SO_X, NO_x, CO, CO_2, H_2O, HC, formaldehyde, PM_{total}, PM_{sul}, $PM_{2.5}$, $PM_{0.1}$) are evaluated. The total NO_x emissions induced by Turbofan 1 and Turbofan 2, are 31.6362 kg and 17.2384 kg, respectively (Total NO_x emission difference based on annual domestic air traffic is 73.8895 tons). The total CO_2 emissions induced by Turbofan 1 and Turbofan 2, are 5,744.659 kg and 4,480.5296 kg, respectively (Total CO_2 emission difference based on annual domestic air traffic is 6.4875 k tons). The total SO_x emissions induced by Turbofan 1 and Turbofan 2, are 1.527 kg and 1.191 kg, respectively (Total SO_x emission difference based on annual domestic air traffic is 1.7243 tons). The total $PM_{2.5}$ emissions induced by Turbofan 1 and Turbofan 2, are 0.2368 kg and 0.1624 kg, respectively (Total $PM_{2.5}$ emission difference based on annual domestic air traffic is 0.3818 tons). The total emissions induced by Turbofan 1 and Turbofan 2, are 8,034.7811 kg and 6,260.2928 kg respectively (Total total emission difference based on annual domestic air traffic is 9.1066 k tons). The HSR trip-related emissions are also calculated, and emissions value and travel time are presented in Table 5 for narrow-body aircraft, regional jets, and HSR.

Table 5. Released emissions value and travel time based on transportation modes

Transportation Mode	**Narrow-Body Aircraft**	**Regional Jet**	**HSR**
Released emissions (k tons)	41.234	32.127	12.540
Number of trips*	5,132	5,132	1,529
Route travel time	40 min.	40 min.	4 hr. 40 min.
Needed travel time**	2 hr. 10 min.	2 hr. 10 min.	4 hr. 55 min.

*Number of trips calculated based on 640,557 passengers
(A total of 640,557 passengers carried out a flight from/to Konya Airport in 2022).
**Travel time includes boarding and check-in.

A modal shift from airways to railways needs to be required on selected destinations by adding additional trips. A modal shift from short-haul flights to HSR needs to be carried out for releasing less emissions. To carry 640,557 passengers with HSR (419 passenger capacity), 1,529 trips are needed, and these trips cause about 12.540 k tons of electricity production-related emissions annually (8.2 tons emissions per trip). A total of 28.694 k tons of emissions can be reduced by adding 1,529 additional HSR trips on selected destinations annually. Approximately 3.3 times more green travel can be achieved with HSRs than the currently used narrow-body passenger aircraft. Emissions from HSR can be further reduced by using renewable energy sources in the production of electricity required for HSR. Traveling with HSR seems the most eco-friendly travel option among the other travel options due to the high load factor. It is also superior to air transportation in terms of energy consumption, and monetary efficiency. Although HSR requires additional investment costs in providing the needed infrastructure, they have increased their preferability as they are faster and safer than the highways, cheaper than the airlines, and provide the opportunity to travel with lower energy. However, noise costs over longer distances are higher in HSR. Therefore, speed is limited in crowded places, tunnels, and bridges where lines pass, to prevent security and noise-related disturbances. On the contrary, noise costs do not depend on distance when traveling with airways because aviation-related noise only occurs during take-off and landing [38].

4. CONCLUSION

One of the most important factors in greenhouse gas release is the transportation sector after electricity generation and heating. In recent years, parallel to the developments in the aviation sector, while airports have positively affected the economic development of the regions they are located in, they also negatively affect the environment. Aviation-based air pollution, which is formed because of the number of landings/take-offs and the fuel consumed by aircraft during the cruising stages, affects climate change. To reduce the negative impacts of these emissions, strategies should be followed in parallel with technological developments. In this study, the environmental effect of narrow-body passenger aircraft, regional jets, and HSR are investigated. Travel option-based emissions for the City of Konya in Turkey have been analyzed in detail. The study concludes that the preference for regional jets instead of narrow-body aircraft burns less fuel and emits less emissions. To explain specifically, regional jets should be preferred for regional flights to airports where the passenger density per aircraft is low, instead of narrow-body passenger aircraft added to their fleets by airline operators for use in both regional and international flights. In this way, the fuel burned and the emissions released to nature can be reduced for the same route. The Turkish civil aviation authority (SHGM) needs to conduct a vision study to re-examine existing aircraft and implement emission restrictions. Aircraft load factor should be adjusted to higher levels and the number of flights should be arranged in such a way that transportation is not affected. In addition, the results imply the environmental impact of airways is much more than railways on the same route. Railways which is alternative to the airways can be encouraged for more green travel between selected destinations. A modal shift from airways to railways needs to be required by adding additional trips by TCDD which is an official railway operator in Turkey. While the capacity can be increased by adding additional trips in the short-term strategy, the existing capacity can be increased by designing new railway networks in the long-term strategy. Of course, the aircraft is used as the best travel option where travel time is important. However, flying with regional jets which have less maximum take-off weight from/to airports with low passenger density will significantly reduce the amount of emissions. In addition, for trips where travel time is not so important, choosing HSR stands out as the best environmentally friendly travel method. In future studies, a more detailed study is planned for each airport according to each aircraft type.

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DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare 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 and wrote the manuscript.

Omer Cam: Design all the materials and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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