Araştırma Makalesi / Research Article

Determining of Aircraft Engine Greenhouse Gas (CO_2, CH_4 and N_2O) Emissions from the Landing and Take-Off Operations Around the Airport Area

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Abstract
Recently, environmental concerns arising from aviation activities have increased, and studies on the environmental aspect of aircraft operations within the concept of sustainable and cleaner aviation have become one of the important research topics. In this study, the greenhouse gas (GHG) Emissions, namely CO_2, CH_4, and N_2O pollutants emitted to the environment during the landing and take-off operations in the International Eskisehir Hasan Polatkan Airport (LTBY) of aircraft engines were analyzed with the help of predictive approaches. Additionally, the average jet-fuel consumptions of these aircraft were determined. Calculations were performed in point of the method of the Intergovernmental Panel on Climate Change (IPCC) and performed with the Tier-2 predictive approach. According to results, it has been obtained that the Airbus 321 (A-321) series aircraft has the highest pollution with a value of 762495 kg/y of GHG. Furthermore, it has been observed that approximately 1127710 kg/y of CO_2, 48.14 kg/year of CH_4, and 39.77 kg/y of N_2O were released into the environment. On the other hand, the total value of jet-fuel consumption during the landing and take-off operations of these aircraft is calculated to be an average of 357500 kg/y. In this regard, it has been determined that the Boeing B767-300 series aircraft (B763) is the most inefficient type of aircraft depending on the fuel consumption by performing a correlation between the parameters of average jet-fuel consumption and total landing and take-off count.

Keywords: Aircraft Engines, Aviation Emissions, Greenhouse Gases (GHG), Landing-Take-Off Cycle, Environmental Impact, Sustainable Aviation.

Havalimanı Bölgesinde İniş ve Kalkış Operasyonlarından Kaynaklanan Uçak Motoru Sera Gazı (CO_2, CH_4 ve N_2O) Emisyonlarının Belirlenmesi

Öz
Son zamanlarda havacılık faaliyetlerinden kaynaklanan çevresel kaygılar artmış ve sürdürülebilir ve daha temiz havacılık konsepti içerisinde havacılığın çevresel boyutuna yönelik olarak yapılan çalışmalar önemli araştırma konularından birisi haline gelmiştir. Bu çalışmada, Uluslararası Eskişehir Hasan Polatkan Havalimanı'nda (LTBY) iniş ve kalkış operasyonları sırasında uçak motorlarından çevreye yayılan ve sera gazı emisyonları olarak bilinen CO_2, CH_4 ve N_2O kirleticileri, tahmin yaklaşımları yardımıyla analiz edilmiştir. Ek olarak, incelemeye konu uçakların uçuşun bu fazında toplamda yaklaşık jet yakıtı tüketim değerleri incelenmiştir. Hesaplamalar, IPCC (Hükümetler arası İklim Değişikliği Paneli) yöntemi ışığında ve Tier-2 tahmin yaklaşımıyla gerçekleştirilmiştir. Elde edilen sonuçlara göre Airbus 321 (A-321) serisi uçakların toplamda 762495 kg/yıl sera gazı emisyonu salınım değeri ile en yüksek kirliliğe sahip olduğu ortaya çıkmıştır. Ayrıca incelemeye konu uçaklardan iniş ve kalkış operasyonları neticesinde çevreye yaklaşık olarak 1127710 kg/yıl karbondioksit (CO_2), 48.14 kg/yıl metan (CH_4) ve 39.77 kg/yıl diazot monoksit (N_2O) salındığı görülmüştür. Öte yandan bu uçakların iniş-kalkış operasyonları sırasında jet yakıtı tüketiminin toplam değeri yaklaşık olarak 357 ton/yıl olarak hesaplanmıştır. Bu bağlamda, ortalama Jet yakıtı tüketimi ile toplam iniş kalkış operasyonu sayıları arasında korelasyon kurularak Boeing B767-300 (B763) serisi uçağın hesaplanmış olan yakıt tüketim performansına bağlı olarak en verimsiz uçak tipi olduğu tespit edilmiştir.

Anahtar kelimeler: Uçak Motorları, Havacılık Emisyonları, Sera Gazları, İniş-Kalkış Döngüsü, Çevresel Etki, Sürdürülebilir Havacılık.

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1. Introduction

In recent years, the share of the aviation industry in the world economy has increased and airline traffic has increased significantly. For example, in the period between 1989 and 2009, the total planned airline traffic grew by an annual average of 4.4%. In 2009, approximately 2.3 billion passengers and 38 million tons of cargo were transported by airlines around the world [1, 2]. It is known that approximately 32 million people are working in the aviation sector in the world, and the aviation industry has a size of 3.6 billion dollars [3,4]. The aviation industry accounts for 2% of overall CO_2 pollutants, also it is predicted that this value will reach 3% by 2050 [4, 5]. In addition to some negative environmental effects brought about by this growth in the aviation sector, it also has several adverse effects on human health, directly or indirectly. Concepts such as emission and noise can be given as examples [6, 7].

The environmental impacts of aircraft-induced emissions are categorized in two different ways. One of them is the landing and take-off cycle called LTO. The landing and take-off cycle includes four phases of flight. These are taxi, take-off, climb and approach phases. This cycle includes aircraft movements up to 915 meters above the ground. The effect of emissions from aircraft around the airports is largely due to this cycle. Another way to examine the environmental impact of aircraft emissions is the cruise phase of flight. Cruise is a flat flight mode that takes place above 915 meters altitude. Cruise emissions directly cause climate change, stratospheric ozone, which is one of the layers of the atmosphere, and UV radiations [8-10]. Different types of exhaust emissions and pollutants are released into the atmosphere during the landing and take-off cycle from aircraft. It is known as CO_2, H_2O, NO_X, SO_X, CO, HC, VOC, NMVOC, and other gases and particulates. CO_2, CH_4 N_2O gases, which are called greenhouse gas emissions, are among the gases released [11-15].

In the literature, it has been observed that studies on aircraft emissions have become widespread in recent years. Kaygusuz [16] has identified in his 2001 study of air for his release during take-off and landing cycle emissions of NO_X and CO emissions that form part 0.25%-0.3% of total emissions in Turkey.

Tokuslu [17] estimated NOx, CO, and HC pollutants at Tbilisi International Airport in Georgia from aircraft during the LTO cycles for the year 2018. The author used the International Civil Aviation Organization (ICAO) engine exhaust emission databank to calculate aircraft-induced emissions in his study. According to the results of the study, the total aircraft emissions during the LTO cycle were estimated to be 428.78 t/year (20.24 t/year for HC, 161.21 t/year for CO, and 247.33 t/year for NOx,) at the airport examined. The author argued that the international flight operations were made up of 99% of all flights in terms of total LTO emissions.

Pecorari et al. [14] analyzed the CO, HC, and NO_X emissions from aircraft with the help of the Lagrangian particle method. Uygur and Ozgunoglu [15] examined the CO_2, NMVOC, CH_4 N_2O, NO_X, CO, and SO_2 gaseous generated during the LTO cycles of aircrafts at Kahramanmaraş Airport in 2016. According to the results of the examination, they determined that the type of aircraft that generates the most emission is Airbus 320 (A320). Kumas et al. [18] determined the CO_2 emission amount for 2017 at Muğla Dalaman Airport as 93410.750 tons per year as a result of their calculations. Yılmaz [19] calculated the NO_X, HC, and CO emissions at Kayseri Airport during the landing and take-off cycles of the aircraft in 2010 in parallel with the emission inventory of ICAO and stated that a total of 177.90 tons of emission was emitted to the environment in 2010.

Rismann et al. [20] analyzed by using the model of Advanced Transportation Modeling System, Emission, Response and Reactions of Atmospheric Matter (AMSTERDAM), to analyze the emissions resulting from the landing and take-off cycle at Atlanta Airport (USA).

Dong et al. [21] assessed whether flight frequency has substantial effects on air pollution depending on the monthly data of aircraft movements from 59 airports in China for about 4 years by using the two-way fixed effects model.

In another paper, Phoenix et al. [22] evaluated the global effects of aviation non-LTO emissions on surface air quality for present-day and mid-century (2050) using the Community Atmosphere Model with Chemistry, version 5 (CAM5). Besides, they examined the aviation effect at mid-century with two fuel scenarios, a biofuel, and a fossil fuel. Yang et al. [23] estimated the emissions of air pollutants from aircraft and other sources at Beijing Capital International Airport using aircraft using meteorological data.

In the study, the emitted GHG emissions to the environment during the landing and take-off cycle of the aircraft with used jet-fuel at International Eskisehir Hasan Polatkan Airport (LTBY) are analyzed with the help of predictive approaches. Thirteen different types of aircraft are examined in the analyses. Also, the total average jet-fuel consumptions of these thirteen different types of aircraft are determined. Additionally, by correlating the count of LTO cycles and total fuel consumption, the aircraft type that is the most efficient and inefficient in fuel consumption is determined among the analyzed aircraft types. In this study, different from some previous studies, it is aimed to analyze aviation-induced emissions by considering the more diversity of different types of aircraft. In this manner, it is purposed to make a helpful contribution to the aviation-induced emission literature in terms of different aircraft types. Besides, international flights are also analyzed in addition to the emission evaluations of local-scale flight operations at an airport.

2. Material and Method

2.1. The LTO Cycle and GHG Emissions

An aircraft maintains its flight in two general modes. One of them is the landing-take-off cycle that takes place below 915 meters (3000 feet) and includes taxi, take-off, climb, and landing phases, while the other is the cruise mode, which is called flat flight and is outside the landing-take-off cycle above 915 meters [4, 24]. A visualized information about the landing and take-off cycle of flight, which includes various maneuvers of an aircraft, is given in Figure 1.

Figure 1. LTO cycle of flight [25].

Approximately 10% of all aircraft emissions, excluding HC and CO_2 emissions, are emitted at ground level and during the LTO cycle. Almost 30% of the total HC and CO_2 emissions emitted by the aircraft are emitted in this cycle [4, 26].

Greenhouse gases (GHG) compose a group of gases leading to climate change and global warming. The Kyoto Protocol, an environmental agreement signed by many parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 to curb global warming, includes six greenhouse gases: nitrous oxide (N_2O), methane (CH_4), carbon dioxide (CO_2), and sulphur hexafluoride (SF6). It is possible to compare them and to determine their individual and total contribution to global warming by converting them to carbon dioxide (or CO_2) equivalents [27].

2.2. Method and Analyses

The approach of IPCC, which are concepts that called the Tier methodologies in the assessment of the parameters such as combustion technology, conditions of combustion, standards of emissions resulting from combustion, characteristics of the fuel used in combustion, in emission calculations related to the transportation sector. In the methodology of Tier-1, the emission generated by aircraft landing-take-off and cruise activities in aviation is obtained by multiplying the amount of fuel consumed by aircraft with average emission factors. The equation for the related calculation method is given in Equation (1) [15, 28].

$$Emission\ Amount\ (y) = EI \times FC \qquad (1)$$

Where *EI* denotes the Emission Index which is specifically related to the type of pollutant gas, the unit of this parameter is kg/LTO, the *FC* represents the fuel consumption of an aircraft operating the LTO cycle of flight, the unit of this parameter is kg, and *y* is the yearly emission value.
In the methodology of Tier-2, the landing and take-off cycle emissions of the aircraft are estimated according to Equation (2).

$$LTO\ Emissions\ (y) = LTO\ Count \times EI \qquad (2)$$

Where, while the *LTO Count* demonstrates the number of total Landing and Take-off cycles of an aircraft, *EI* indicates that the emission index which is specifically related to the type of pollutant gas, unit is kg/LTO. In the Tier-2 method, the type of fuel used by aircraft is critical, and according to this method, emission investigations of aircraft using only jet fuel are performed. The aircraft types examined in the study and the values of the GHG emission index are given in Table 1 [15, 28].

Table 1. Examined aircraft types and their GHG emission indexes (EI)

Aircraft type	Aircraft model	CO_2 – EI (kg/LTO)	CH_4 – EI (kg/LTO)	N_2O – EI (kg/LTO)
A319	Airbus A319	2310	0.06	0.1
A320	Airbus A320	2440	0.06	0.1
A321	Airbus A321	3020	0.14	0.1
B734	Boeing 737-400	2480	0.08	0.1
B738	Boeing 737-800	2780	0.07	0.1
B763	Boeing 767-300	5610	0.12	0.2
C25A	CESSNA 525A Citation CJ2	1070	0.33	0.03
B38M	Boeing 737-MAX 8	2780	0.07	0.1
C56X	CESSNA 560X Citation Excel	1070	0.33	0.03
GLF4	Gulfstream 4	2160	0.14	0.1
C680	CESSNA Citation Sovereign 680	1070	0.33	0.03
CRJ2	BOMBARDIER Regional Jet CRJ-200	1070	0.33	0.03
MD82	McDonnell Douglas MD82	3180	0.19	0.1

In Table 1, calculations for thirteen aircraft for which GHG emission indexes are given were determined by the IPCC method and performed with the help of the Tier-2 method. The total LTO cycles of these aircraft in one year are given in Table 2. Flight data of aircraft were obtained from Eskisehir Technical University. The analysis and matching of aircraft types were performed. Besides domestic flights, international flights are also included in the calculations.

Table 2. Aircraft type and LTO count

Aircraft type	Aircraft model	LTO Count
A319	Airbus A319	1
A320	Airbus A320	64
A321	Airbus A321	167
B734	Boeing 737-400	6
B738	Boeing 737-800	125
B763	Boeing 767-300	1
C25A	CESSNA 525A Citation CJ2	3
B38M	Boeing 737-MAX 8	21
C56X	CESSNA 560X Citation Excel	17
GLF4	Gulfstream 4	2
C680	CESSNA Citation Sovereign 680	8
CRJ2	BOMBARDIER Regional Jet CRJ-200	1
MD82	McDonnell Douglas	1

3. Results and Discussion

The estimated GHG emission results with the aid of the Tier-2 method are given in Tables 3-5. Accordingly, the obtained yearly CO_2 emissions based on the aircraft types and their LTO cycles are given in Table 3.

Table 3. Results of emitted CO_2 emissions

Aircraft type	Aircraft model	LTO Count	CO_2 (kg/y)
A319	Airbus A319	1	2310
A320	Airbus A320	64	156160
A321	Airbus A321	167	504340
B734	Boeing 737-400	6	14880
B738	Boeing 737-800	125	347500
B763	Boeing 767-300	1	5610
C25A	CESSNA 525A Citation CJ2	3	3210
B38M	Boeing 737-MAX 8	21	58380
C56X	CESSNA 560X Citation Excel	17	18190
GLF4	Gulfstream 4	2	4320
C680	CESSNA Citation Sovereign 680	8	8560
CRJ2	BOMBARDIER Regional Jet CRJ-200	1	1070
MD82	McDonnell Douglas	1	3180

According to Table 3, the amount of the CO_2 emissions are estimated to be 156160 kg/y for the A320, 504340 kg/y for the A321, 14880 kg/y for the B734, 347500 kg/y for the B738, 58380 kg/y for the B38M, and 18190 kg/y for the C56X types of aircraft. Also, it is revealed that these aircrafts have the major portion of CO_2 emission amount of total amount.

The variation of total CO_2 values by aircraft types is plotted in Figure 2.

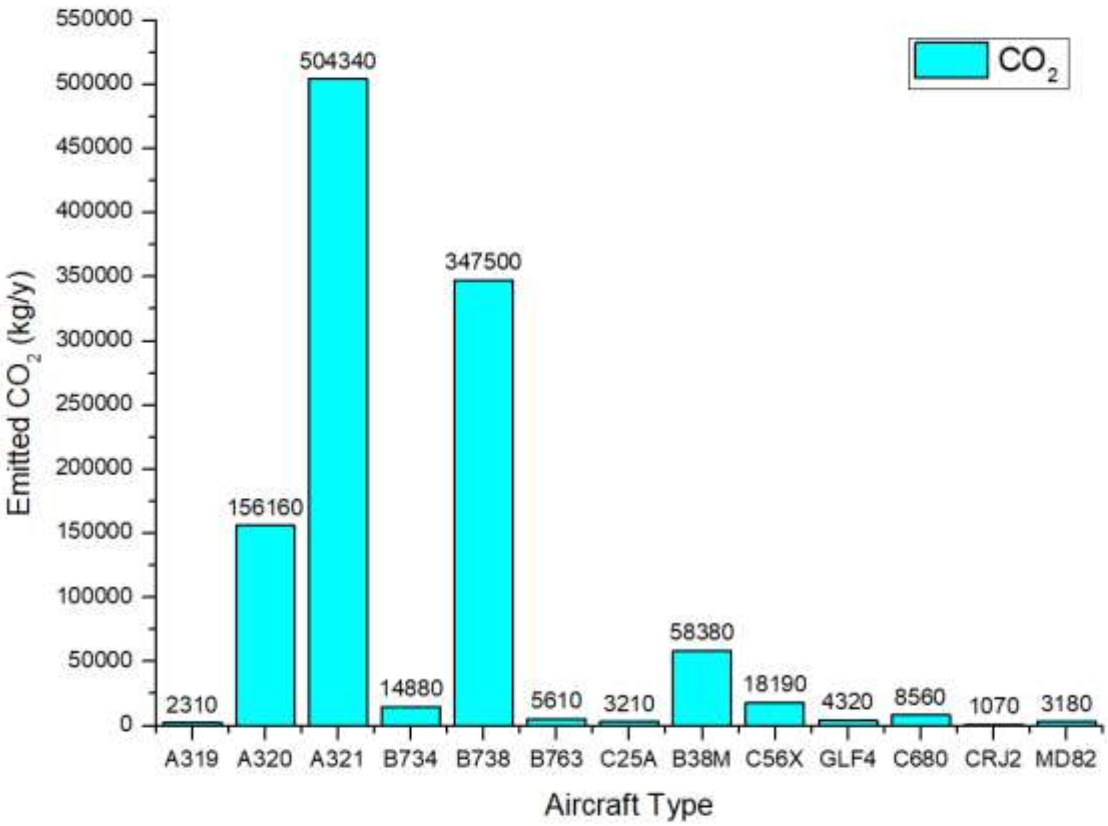

Figure 2. Decomposition of CO_2 emissions based on the aircraft types

According to the plotted graph in Figure 2, the total CO_2 emissions in the period examined are found to be 1127710 kg/y. The highest CO_2 emissions are found to be 504340 kg/y for A321 series aircraft. One of the main reasons for this can be considered to have the maximum LTO count with a value of 167 of A321 series aircraft. Also, the CRJ2 series aircraft has the minimum CO_2 emissions among the other ones with a value of 1070 kg/y.

The obtained yearly CH_4 emissions based on the aircraft types and their LTO cycles are presented in Table 4.

Table 4. Results of emitted CH_4 emissions

Aircraft type	Aircraft model	LTO Count	CH_4 (kg/y)
A319	Airbus A319	1	0.06
A320	Airbus A320	64	3.84
A321	Airbus A321	167	23.38
B734	Boeing 737-400	6	0.48
B738	Boeing 737-800	125	8.75
B763	Boeing 767-300	1	0.12
C25A	CESSNA 525A Citation CJ2	3	0.99
B38M	Boeing 737-MAX 8	21	1.47
C56X	CESSNA 560X Citation Excel	17	5.61
GLF4	Gulfstream 4	2	0.28
C680	CESSNA Citation Sovereign 680	8	2.64
CRJ2	BOMBARDIER Regional Jet CRJ-200	1	0.33
MD82	McDonnell Douglas	1	0.19

According to Table 4, the CH_4 emissions are calculated to be 3.84 kg/y for the A320, 23.38 kg/y for the A321, 0.48 kg/y for the B734, 8.75 kg/y for the B738, 1.47 kg/y for the B38M, 5.61 kg/y for the C56X, and 2.64 kg/y for the C680 types of aircraft.

The variation of total CH_4 emissions by aircraft types is graphed in Figure 3.

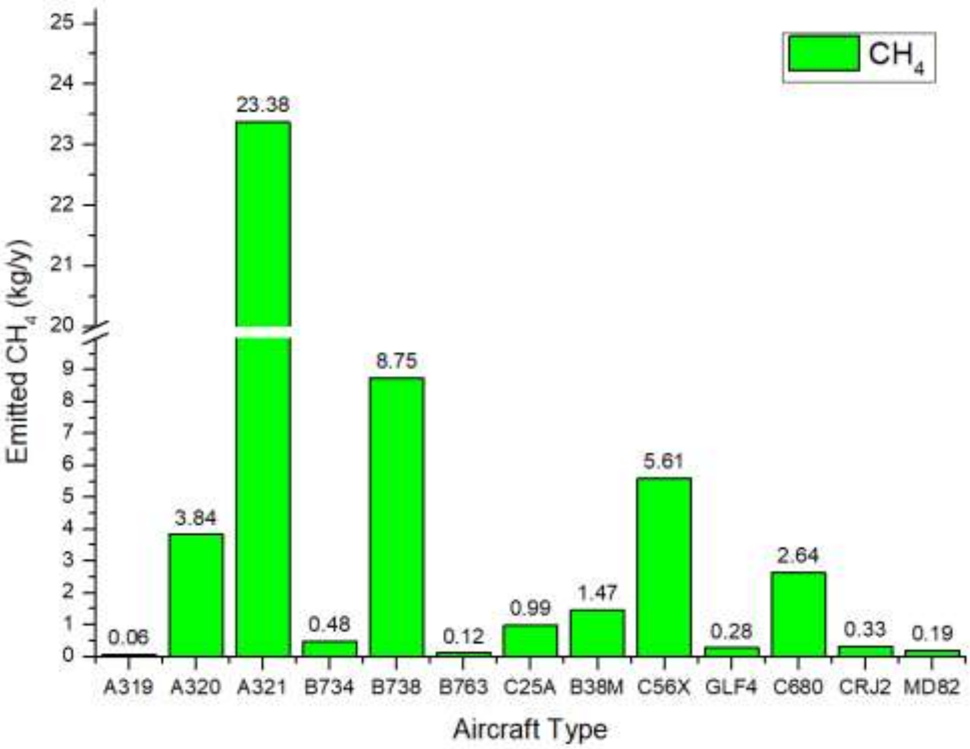

Figure 3. Decomposition of CH_4 emissions based on the aircraft types

Figure 3 denotes that as expected, the A321 series aircraft emitted the most CH_4 emissions with a value of 23.38 kg/y due to the maximum LTO count. The total CH_4 emission in the period examined is found to be 48.14 kg/y. Besides, the A319 series aircraft has the minimum emitted CH_4 emissions among the other ones with a value of 0.06 kg/y.

The obtained yearly N_2O emissions based on the aircraft types and their LTO cycles are demonstrated in Table 5.

Table 5. Results of emitted N_2O emissions

Aircraft type	Aircraft model	LTO Count	N_2O (kg/y)
A319	Airbus A319	1	0.1
A320	Airbus A320	64	6.4
A321	Airbus A321	167	16.7
B734	Boeing 737-400	6	0.6
B738	Boeing 737-800	125	12.5
B763	Boeing 767-300	1	0.2
C25A	CESSNA 525A Citation CJ2	3	0.09
B38M	Boeing 737-MAX 8	21	2.1
C56X	CESSNA 560X Citation Excel	17	0.51
GLF4	Gulfstream 4	2	0.2
C680	CESSNA Citation Sovereign 680	8	0.24
CRJ2	BOMBARDIER Regional Jet CRJ-200	1	0.03
MD82	McDonnell Douglas	1	0.1

According to Table 5, the N_2O emissions are computed to be 6.4 kg/y for the A320, 16.7 kg/y for the A321, 12.5 kg/y for the B738, 2.1 kg/y for the B38M types of aircraft.

The variation of total N_2O emissions by aircraft types is graphed in Figure 4.

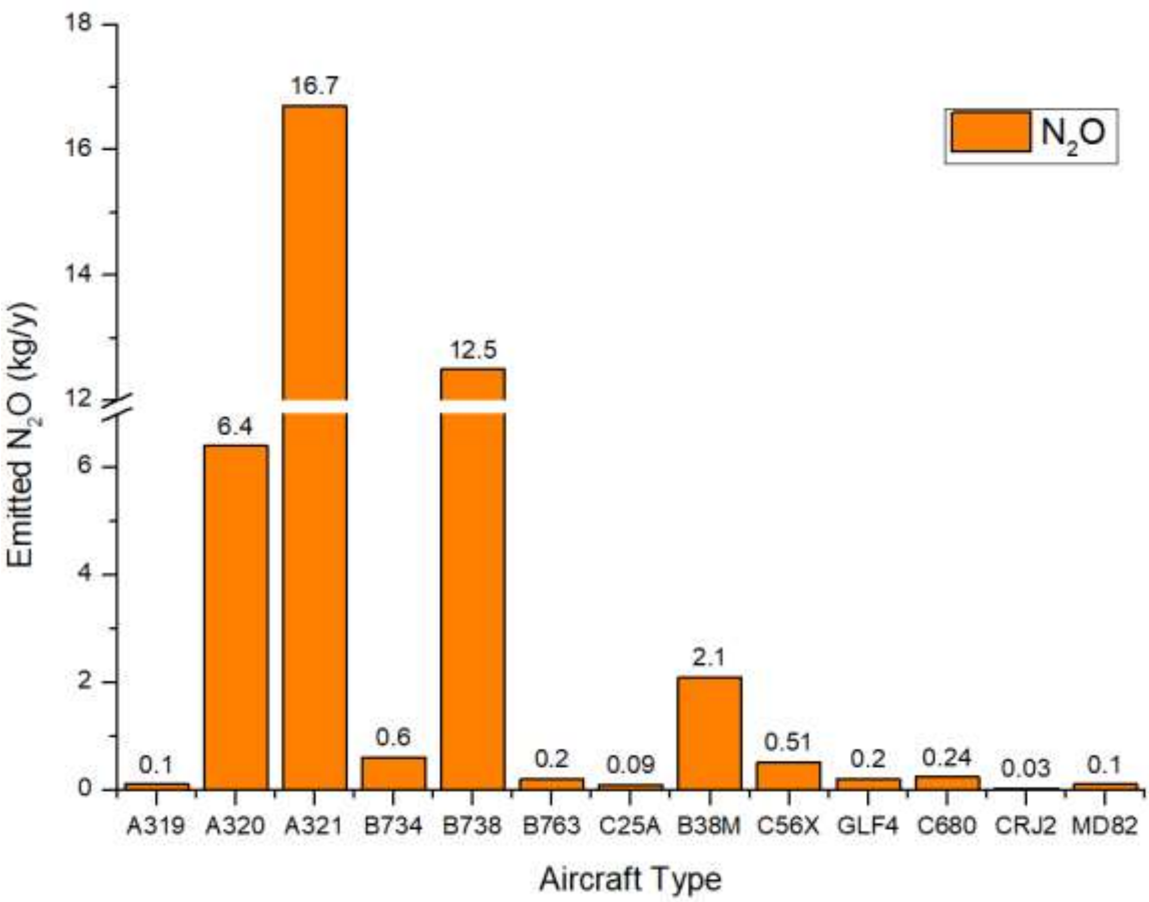

Figure 4. Decomposition of N_2O emissions based on the aircraft types

Figure 4 specifies that when the LTO count is maximum, the A321 series aircraft peaks in terms of N_2O emissions, as with the CO_2 and CH_4 change trend. The A321 series aircraft emitted 16.4 kg/y of N_2O. It is followed by B738 series aircraft with a value of 12.5 kg/y and A320 series aircraft with a value of 6.4 kg/y, respectively. Moreover, the CRJ2 series aircraft has the minimum N_2O emissions among the other ones with a value of 0.03 kg/y. The total N_2O emissions in the period examined are found to be 39.77 kg/y.

When the overall results are reviewed, whereas the MD82 series aircraft has the lowest LTO count, the aircraft emitted a relatively high rate of GHG emissions. One of the main reasons for this can be considered to have the high rate GHG emission indexes with a value of 3180 for CO_2, 0.19 for CH_4, and 0.1 for N_2O of MD82 series aircraft. Similarly, while the CO_2, CH_4, and N_2O emission indexes relatively lower than the Boeing 763 and MD82 series aircraft, the A321 is the highest pollutant aircraft in the period examined because the aircraft has a maximum LTO count. Besides, local and small scale Since the examined airport is local and small in scale and the movement counts of the aircraft are relatively low, the emission values are lower than the other airports in this sense. However, the sustainability of these results and even their reduction is very important in terms of the environmental dimension of aviation.

On the other hand, the total jet-fuel consumption of these aircraft from LTO operations in the period examined was found to be approximately 357500 kg/y. The decompositions of total jet-fuel consumption by aircraft types are given in Table 6 and Figure 5.

Table 6. The variation of Jet fuel consumption values

Aircraft type	Aircraft model	Jet-Fuel Consumption (kg/y)
A319	Airbus A319	730
A320	Airbus A320	49280
A321	Airbus A321	160320
B734	Boeing 737-400	4680
B738	Boeing 737-800	110000
B763	Boeing 767-300	1780
C25A	CESSNA 525A Citation CJ2	1020
B38M	Boeing 737-MAX 8	18480
C56X	CESSNA 560X Citation Excel	5780
GLF4	Gulfstream 4	1360
C680	CESSNA Citation Sovereign 680	2720
CRJ2	BOMBARDIER Regional Jet CRJ-200	340
MD82	McDonnell Douglas	1010

Figure 5 indicates that the A321 series aircraft burned 160320 kg/y of jet fuel. It is followed by B738 series aircraft with a value of 110000 kg/y and A320 series aircraft with a value of 49280 kg/y, respectively. Also, in this period, the jet fuel consumption of B38M, C56X, B734, C680, and MD82 aircrafts are calculated as 18480 kg/y, 5780 kg/y, 4680 kg/y, 2720 kg/y, and 1010 kg/y, respectively. As can be clearly seen that the A321 series aircraft is the most fuel-consuming aircraft among the other ones. One of the main reasons for this result is that the aircraft has 167 LTO.

Average jet-fuel consumption efficiencies are estimated for each of these aircraft based on the LTO operations and calculated jet-fuel consumption values. Average Jet-fuel consumption efficiencies of the aircraft types under-investigated are graphed in Figure 6.

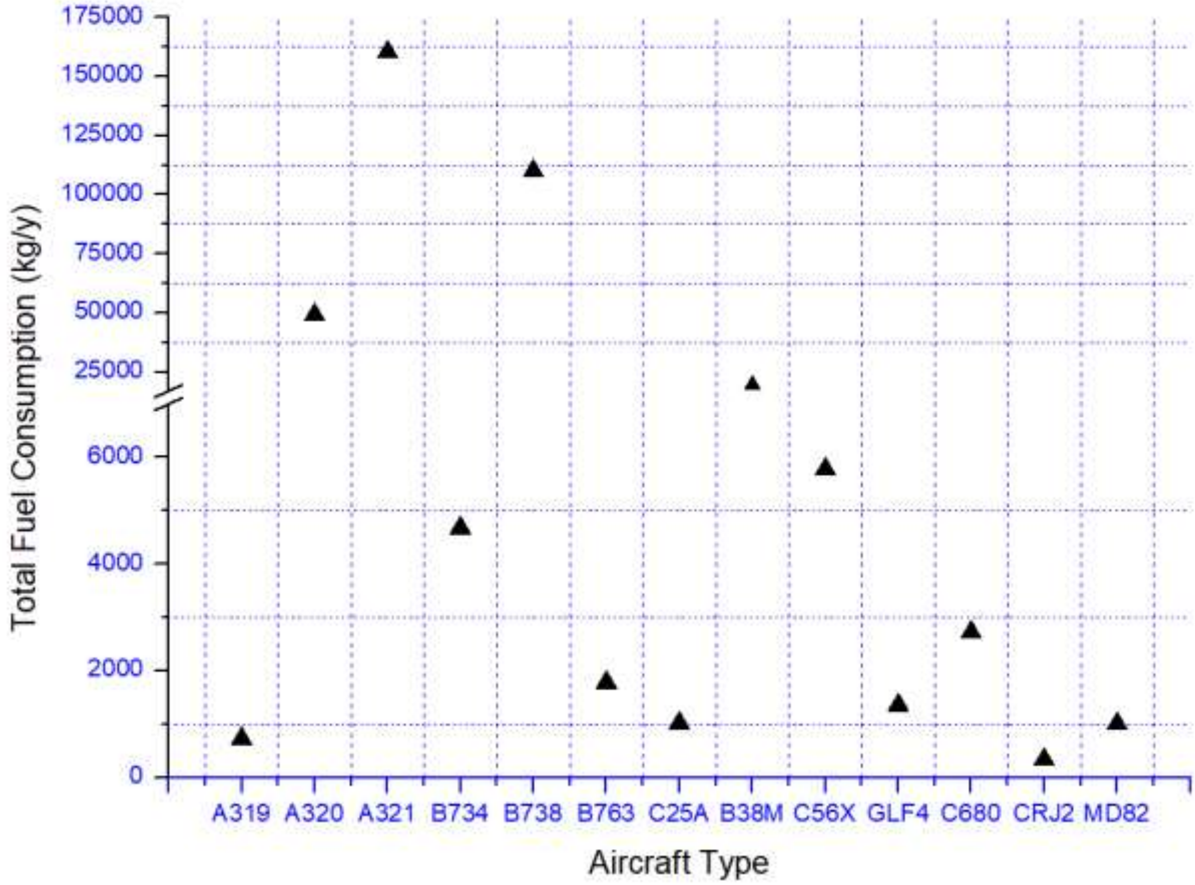

Figure 5. Jet-fuel consumption based on the aircraft types of under-investigated period

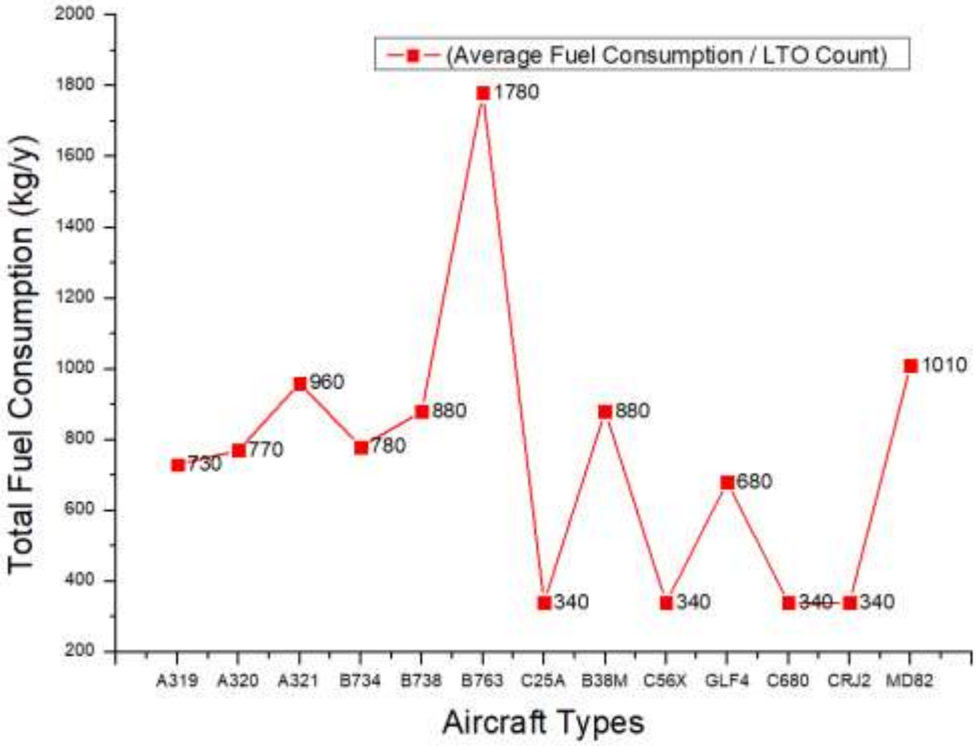

Figure 6. Aircraft engine fuel efficiencies based on the correlation between the count of LTO cycles and total fuel consumption values

According to the plotted graph in Figure 6, for the specified parameter which is the ratio of average jet-fuel consumption to LTO count, the B767-300 series aircraft (B763) is the most inefficient aircraft in terms of fuel consumption efficiency at the end of LTO operations in the period examined and among the aircraft types examined. This is followed by the MD82 series aircraft. Contrary to this trend, it can be concluded that although the B763 has low LTO, the C680, CRJ2, C25A and C56X aircraft are more fuel efficient at almost similar LTOs in view of only this parameter.

4. Conclusion

In the present research, the GHG emissions gases emitted to the atmosphere from the landing and take-off cycle operations of thirteen different types of aircraft at a small-scale airport operating international flights were investigated. The main results of the current study can be summarized as follows:

- It was revealed that Airbus 321 (A321) was the highest GHG generating aircraft type in the period examined. Although the A321's CO_2, N_2O, and CH4 emission indexes are lower than the Boeing 763 (B763) series and MD82 type aircraft, the A321's maximum LTO count has led to this result. It has been found that the aircraft, whose emissions are examined, burned approximately 357500 kg/y of jet fuel in this period.
- Finally, for the specified parameter which is the ratio of average jet-fuel consumption to LTO count, the B767-300 series aircraft (B763) is the most inefficient aircraft in terms of fuel consumption efficiency at the end of LTO operations in the period examined and among the aircraft types examined.

In the coming years, with the increasing of yearly operations at airports worldwide, greenhouse gaseous are expected to rise. It is necessary to take measures to the regulations that prioritize issues such as the gradual decrease of fossil fuels and global climate change, to spread more electric or fully electric aircraft with hybrid propulsion systems, and to minimize both fuel efficiency and environmental impact of aircraft.

In this study, real-time values were used for all computations. The current study and its results will be a key reference for future implementations of aviation-induced emission estimation procedures. Also, for a future study, the author suggests and considers detailed investigating the potential environmental, economical, ecological-cost effects of aviation-induced emissions.

Authors' Contributions

All contributions belong to the author in this paper.

Statement of Conflicts of Interest

There is no conflict of interest among the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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