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# ENVIRONMENTAL IMPACT AND COST ASSESSMENT OF COMMERCIAL FLIGHT INDUCED EXHAUST EMISSIONS AT ISPARTA SÜLEYMAN DEMIREL AIRPORT

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**Keywords**
*Environmental Impact, Emissions, Cost, Aviation, Aircraft Engine.*

**Abstract**
Airway is one of the widely preferred transportation in Turkey since investment in the sector in the last decade. Increase in interest to airway causes more energy consumption and emissions. Thus evaluation of air transportation induced emissions draws attention of researchers. In this framework the current paper discusses environmental and economic evaluation of emissions from aircraft in Isparta Süleyman Demirel Airport in 2018. At the end of the study March month of the year is determined to be the period that environmental impact and environmental cost reach peak point.

# ISPARTA SÜLEYMAN DEMİREL HAVALİMANINDA TİCARİ UÇUŞLAR KAYNAKLI EGZOZ EMİSYONLARININ ÇEVRESEL ETKİLERİ VE MALİYET DEĞERLENDİRMESİ

**Anahtar Kelimeler**
*Çevresel Etki, Emisyon, Maliyet, Havacılık, Uçak Motoru.*

**Öz**
Son yıllardaki havacılık alanına yapılan yatırımlar nedeniyle Türkiye'de havayolu yaygın olarak tercih edilen ulaşım yollarından birisidir. Havayoluna olan ilginin artışı daha fazla enerji tüketimi ve emisyonların oluşmasına sebep olmaktadır. Bu nedenle hava taşımacılığından kaynaklı emisyonların incelenmesi araştırmacıların dikkatini ve ilgisini çekmektedir. Bu çerçevede bu çalışma 2018 yılında Isparta Süleyman Demirel Havaalanı'nda uçaklardan kaynaklanan emisyonların çevresel ve ekonomik değerlendirmesini ele almaktadır. Çalışma sonucunda Mart ayı çevresel etki ve çevresel maliyetlerin en üst noktaya ulaştığı dönem olarak belirlenmiştir.

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## 1. Introduction

Air way is commonly preferred transportation option for providing time saving and being comfy lately. Another reason of interest to air transportation is prevalence of airports worldwide, particularly in Turkey since 2005. If investment of Turkish government in transportation sector in the last decade is considered accessibility to air transportation is an expected situation. According to the statistical data released by General Directorate of State Airports Authority (2020) total air passenger number has increased 102% from 2010 to 2019 whereas number of total flights has risen 67.4% in the same time period. On the other hand global air passenger number annual rise rate in the last ten years is averagely 5.6% whereas this rate for Turkey is 8.1% (ICAO, 2019; General Directorate of State Airports Authority, 2020).

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Growth rate of air transportation both globally and locally in Turkey also induce some major issues such as depletion of energy resources, global warming, climate change and so on (Konuralp, 2020; Lee et al., 2009; Terrenoire et al., 2019). For this reason, numerous studies on energy consumption related environmental impact of air transportation, particularly focusing on aircraft emissions, have been presented to the literature. Elbir (2008) presented estimation of aircraft emissions at Adnan Menderes Airport for the year of 2004. For this purpose, recorded emissions data of landing and take-off was used. At the end of the study annual emissions at full capacity operation conditions of airport were reported. Similarly, Yilmaz and İlbas (2012) discussed exhaust emissions of commonly used and still in service aircraft engines in their paper. Within this context authors compared engine emissions and fuel consumptions using ICAO databank at varying engine power setting. Ekici et al. (2013) noted growth rate of aviation fleet in Turkey and evaluated aircraft emissions in the busiest five airports in Turkey for the year of 2012. Authors concluded Atatürk Airport to be the main pollution source among evaluated airports. Miyoshi and Mason (2013) introduced carbon foot print estimation of passengers at Manchester Airport. According to the main findings of the study drop-off and pick-up, and minicab users were determined to be main source of the high carbon emissions and environmental damage cost. In another paper (Unal et al., 2014) Nevşehir Kapadokya Airport was evaluated in terms of emissions and noise regarding Green Airport requirements of the authority. To calculate emissions in the airport methodology asserted by IPCC was employed. In addition to aircraft emissions emitted gases from heat center of the airport was also considered. Altuntas (2014) calculated global warming potential value for aircrafts in service of domestic flights across Turkey. As a result of the study global warming potential per passenger from 2002 to 2012 was found to be 15.35 $CO_2e$. Koudis et al. (2017) asserted to reduce engine thrust settings at ground operation for pollutant emissions reduction at airports. In this manner flight data records of London Heathrow Airport were used to analyze impact of reduced take-off. At the end of the study fuel consumption and nitrogen oxide emissions were found to be reduced 1-23.2% and 10.7-47.7%, respectively. Evertse and Visser (2017) developed a taxi movement planning system for aircrafts to minimize emissions induced by taxi operations in the airports. Authors recommended this tool to be beneficial for busy airports facing dense traffic due to stringent environmental regulations. Yilmaz (2017) evaluated aircraft emissions in Kayseri Airport for the year of 2010. At the end of the study decrease of 2 minutes in taxiing time was concluded to lead approximately 4% reduction of landing and take-off emissions whereas 25% rise in LTO cycles was found to cause approximately 11% increase emissions. Ozgunoglu and Uygur (2017) discussed aircraft emissions at Kahramanmaraş Airport in 2016 with the aid of tier approach of IPCC. Authors deduced to validate and improve the analysis by experimental studies with the intent of elimination of calculation deficiency. Yang et al. (2018) discussed emissions at Beijing Capital International Airport, the second busiest airport on the earth. Nitrogen oxide emissions were found to be emitted mostly during take-off and climb-out phases of flight whereas carbon monoxide and hydrocarbon emissions were determined to be emitted at taxiing. Another study (Kuzu, 2018) presented aircraft emissions in Atatürk International Airport. According to the research nitrogen oxide, carbon monoxide, and hydro carbon emissions were calculated to be 4249, 2153, and 181 tons annually, respectively. Additionally, climb phase of flight was determined to be the main source of nitrogen oxide emissions. Chilongola and Ahyudanari (2019) presented emissions evaluation for Juanda International Airport Indonesia. Advanced ICAO LTO cycle method was employed during the research. Makridis and Lazaridis (2019) employed AERMOD Gaussian dispersion model for determination of pollutants from aircraft in Chania airport. According to the findings concentration of pollutants were determined to be lower than air quality threshold values. As it is comprehended from the literature survey many more latest studies relevant to topic can be accessed (Zhang et al., 2019; Li, et al., 2019; Zhou et al., 2019; Taghizadeh et al., 2019; Kumas et al., 2019; Xu et al., 2020a, Xu et al., 2020b). In other respects, most of the studies reveal aircraft emissions at airports amount while limited number of papers discuss environmental impact and economics of emissions.

The main goal of the current paper is introducing emissions, environmental impact and economics of emissions at Isparta Süleyman Demirel Airport. Thus real time recorded data is used to evaluate environmental and economical aspects of commercial flights induced aircraft engine emissions using a novel approach. Differently from previous studies environmental impact, and environmental impact cost values are calculated in addition to carbon foot print values.

## 2. Materials and Method

Air transportation passenger number variation with years in Turkey is plotted in Fig. 1. According to the plot approximately half of the passengers in each year is international whereas the other half is domestic passenger.

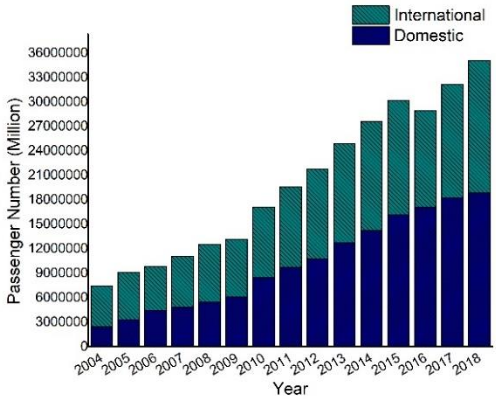


**Figure 1.** Airway Passenger Number in Turkey by years (TSI, 2020)

Isparta Süleyman Demirel Airport was established in 1997 at Keçiborlu district of Isparta (37°51`21"N, 30°22`01"E). ICAO code of the airport is LTFC whereas it is coded to be ISE by IATA. The airport mostly serves to flight training schools as well as it is open to domestic and international flights. Passenger density and commercial flight traffic in the airport is lower than average value of Turkey. If Figs. 1 and 2 are compared this implication can easily be addressed. On the other hand, total take-off count in Isparta Süleyman Demirel Airport is 23,131 while overall take-off count in Turkey is 1,544,169 by the end of 2018.

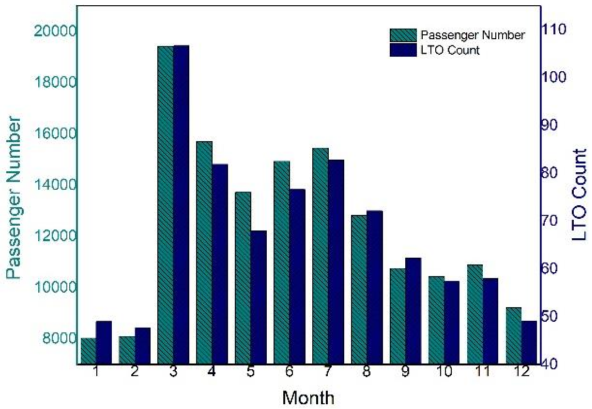


**Figure 2.** Airway Passenger Number and LTO Count in ISE Airport in 2018

In the current study environmental impact and economics of emitted exhaust gases from aircraft at Isparta Süleyman Demirel Airport during the landing and take-off cycle are evaluated. For this purpose, real time recorded emissions data obtained from Ministry of Transport and Infrastructure of the Republic of Turkey is analyzed. According to the provided data total take-off count of commercial flights (excluding training, private, military flights) is 812 while commercial flight passenger number is 149,458 in 2018. In Fig. 2 monthly variation of take-off count and passenger number of commercial flights is plotted. The data set also includes airway company, type of aircraft and its engine, passenger number, count of landing and take-off, average time of each flight phase during landing and take-off, mass flow rates of fuel consumption as well as unburned hydrocarbon, nitrogen oxide, and carbon dioxide emissions during the landing and take-off cycle. Distribution of aircraft type and take-off count of each aircraft type evaluated in the framework of the study are listed in Table 1.

**Table 1.** Data of Examined Aircraft Types

| Type | Number | Take-Off Count |
|---|---|---|
| A330-200 | 12 | 122 |
| A340-300 | 1 | 1 |
| A319 | 13 | 113 |
| A320 | 20 | 241 |
| A321 | 14 | 58 |
| B737-700 pax | 4 | 10 |
| B737-800 | 14 | 197 |
| B737-900 | 5 | 11 |
| MD82 | 6 | 28 |
| MD83 | 9 | 30 |

### 2.1. Environmental Impact Assessment

Environmental impact assessment of aircraft induced emissions in Isparta Süleyman Demirel Airport is performed using two indicators: carbon foot print, and environmental impact factor.

**Table 2.** Carbon Foot Print of Emissions (IPCC, 2019)

| Emissions | Carbon Foot Print ($CO_2e$/kg) |
|---|---|
| CO | 1 |
| $CO_2$ | 1 |
| UHC | 21 |
| $NO_x$ | 310 |

Carbon foot print calculation methodology follows global warming potential for 100 years value. According to this approach contribution of each gas to the global warming is evaluated relatively to carbon dioxide. In Table 2 carbon footprint value of emitted gases is given. To calculate carbon footprint following statement can be written:

$$CFP = \sum m_i cfp_i \quad (1)$$

Here $CFP$ notates total carbon footprint of emissions whereas $cfp_i$ is the carbon footprint of each emission gas.

**Table 3.** Eco-Indicator of Emissions (Meyer et al., 2009)

| Emissions | Specific Environmental Impact Factor (mPts/kg) |
|---|---|
| CO | 8.363 |
| $CO_2$ | 54.545 |
| UHC | 114.622 |
| $NO_x$ | 2749.360 |

Environmental impact of emissions is measured in terms of eco-indicator values. These values listed in Table 3 indicate the bad effect on the environment in terms of life cycle assessment studies. Environmental impact of emissions is calculated by:

$$B = \sum m_i b_i \quad (2)$$

In Eq. 2 $B$ is the total environmental impact of emissions whereas $b_i$ represents specific environmental impact factor of each emitted gas.

### 2.2. Cost Assessment

Eco-cost approach is preferred in the present paper to determine cost of emissions from aircraft engines in the airport. Eco-cost value of each emissions is listed in Table 4. The eco-cost value fundamentally indicates preventing cost of emissions formation and it is found by:

$$C = \sum m_i c_i \quad (3)$$

whereas $C$ and $c_i$ are total eco-cost of emissions and eco-cost value of each emissions.

**Table 4.** Eco-Cost Values of Emissions (Vogtlander, 2019)

| Emissions | Eco-Cost Value (€/kg) |
|---|---|
| CO | 0.27 |
| $CO_2$ | 0.116 |
| UHC | 3.538 |
| $NO_x$ | 6.65 |

## 3. Results and Discussion

In the current paper environmental and economic aspects of commercial flights induced aircraft engine emissions are investigated. In this regard real time recorded emissions data obtained from Ministry of Transport and Infrastructure of the Republic of Turkey is analyzed. To measure the environmental impact of the emissions carbon foot print and environmental impact values are calculated. Main findings of the study are also summarized in

Table 5. In Table 5 sum of carbon foot print, environmental impact and environmental cost is listed dependent to months. For a better understanding first line of the second column can be addressed to be total carbon foot print of commercial flights during the first month of the year 2018.

**Table 5.** Environmental and Economic Results

| Month | Carbon Foot Print ($kg\ CO_2e$) | Environmental Impact (mPts) | Environmental Cost (€) |
|---|---|---|---|
| 1 | 274511.855 | 7278716.844 | 16048.293 |
| 2 | 292062.446 | 7639303.558 | 16830.801 |
| 3 | 721519.972 | 19248107.562 | 42395.984 |
| 4 | 615529.288 | 15999679.456 | 35372.470 |
| 5 | 560417.386 | 14393353.248 | 31838.879 |
| 6 | 590862.564 | 15350739.364 | 33901.083 |
| 7 | 600194.425 | 15732551.511 | 34770.613 |
| 8 | 480196.668 | 12743253.013 | 28140.928 |
| 9 | 393776.800 | 10478462.198 | 23145.695 |
| 10 | 399401.209 | 10268514.603 | 22689.599 |
| 11 | 417601.950 | 10842572.657 | 23910.334 |
| 12 | 349066.370 | 9068277.737 | 19997.671 |

In Fig. 3 monthly variation of carbon foot print of total emissions through year is plotted. As an expected result tendency of carbon foot print variation reaches to peak at the month when take-off count is maximum. On the other hand, carbon foot print is lower in January, February, and December months relatively to other months of the year. Total carbon foot print of emitted gases through the year is also calculated to be 5695140.933 kg $CO_2e$ while CO, HC, $CO_2$, and $NO_x$ is responsible of total carbon foot print by percentages of 0.07%, 0.20%, 37.89%, and 61.82%, respectively.

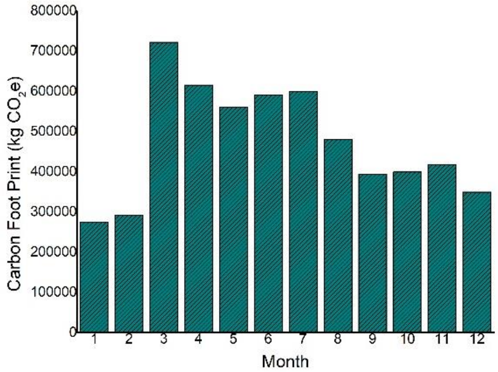


**Figure 3.** Monthly Variation of Carbon Foot Print

According to plotted monthly variation of environmental impact in Fig. 4 the highest environmental impact is found to be 19248107.562 mPts in the March. Maximum take-off count in March is the main reason of that can be considered.

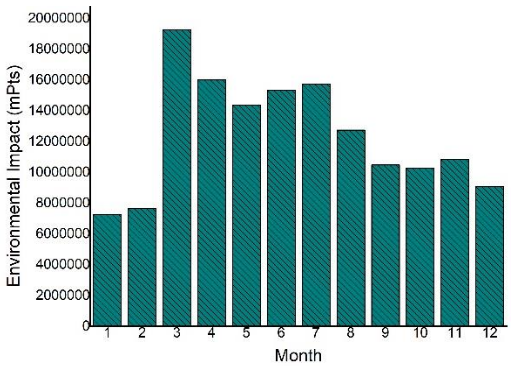


**Figure 4.** Monthly Variation of Environmental Impact

Monthly variation of environmental cost is graphed in Fig. 5. As it is comprehended tendency of Figs. 4 and 5 are similar due to monthly emissions variation. According to Fig. 5 the highest environmental cost is found to be 42395.984 Euro in the March whereas the minimum value is 16048.293 Euro.

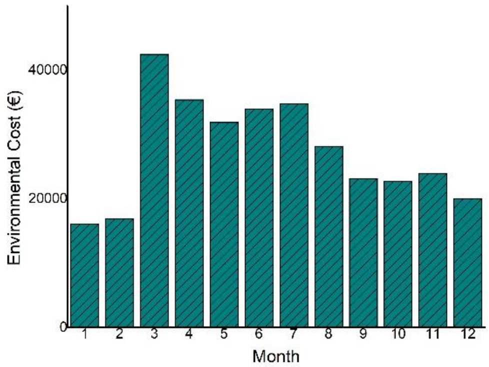


**Figure 5.** Monthly Variation of Environmental Cost

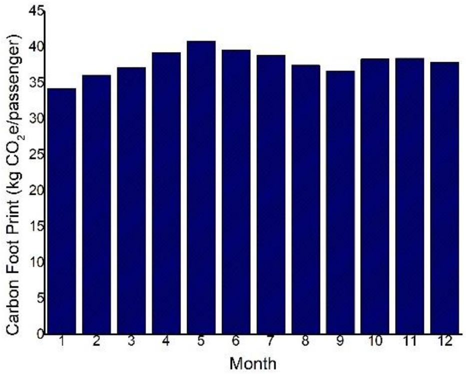


**Figure 6.** Monthly Variation of Carbon Foot Print per Passenger

Fig. 6 demonstrates monthly variation of carbon foot print per passenger. Maximum carbon foot print per passenger is calculated to be 40.841 kg $CO_2e$ in May whereas the minimum value is found to be 34.203 kg $CO_2e$ in the month of January. Similar to carbon foot print per passenger environmental impact per passenger is graphed in Fig. 7. The highest environmental impact of each passenger is calculated to be 1048.925 mPts while the lowest environmental impact of each passenger is 906.892 mPts.

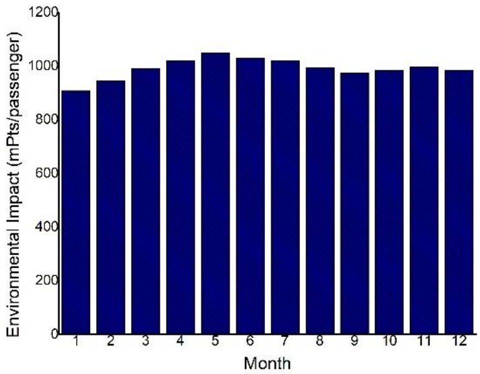


**Figure 7.** Monthly Variation of Environmental Impact per Passenger

Fig. 8 is plotted to show monthly variation of environmental cost per passenger. As it is expected tendency of environmental cost per passenger is same to both carbon foot print per passenger and environmental impact per passenger. Maximum environmental cost per passenger is determined to be 2.320 Euros whereas it is reduced to 2.000 Euros in January.

If passenger-based results are evaluated monthly variation of each indicator is related to both take-off count and passenger number. For this reason Fig. 2 should be re-considered for a better understanding. Even overall indicators reach to peak in March month the gap between take-off count and passenger number in May leads maximum value of indicators per passenger. On the other hand small gap between take-off count and passenger number is the main reason of the approximate value of indicators per passenger through the year excluding month of May. Calculated indicators per passenger are also summarized in Table 6.

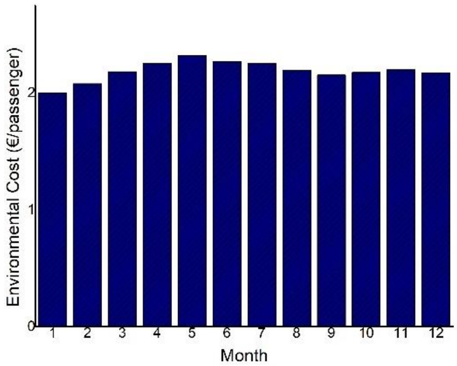


**Figure 8.** Monthly Variation of Environmental Cost per Passenger

In addition to passenger based evaluation of results, findings can be discussed regarding domestic and international flights. 40.38% of total passengers flew internationally whereas 59.61% is domestic passenger. On the other hand carbon foot print of international flights is 2647493.06 kg $CO_2e$ while domestic flights have carbon foot print of 3047647.87 kg $CO_2e$. Additionally environmental impact and environmental cost of international flights are 67861168.79 mPts and 149678.854 Euros, respectively.

**Table 6.** Passenger Based Environmental and Economic Results

| Month | Carbon Foot Print (kg $CO_2e$/passenger) | Environmental Impact (mPts/passenger) | Environmental Cost (€/passenger) |
|---|---|---|---|
| 1 | 34.203 | 906.892 | 2.000 |
| 2 | 36.079 | 943.706 | 2.079 |
| 3 | 37.144 | 990.894 | 2.183 |
| 4 | 39.176 | 1018.310 | 2.251 |
| 5 | 40.841 | 1048.925 | 2.320 |
| 6 | 39.576 | 1028.181 | 2.271 |
| 7 | 38.848 | 1018.288 | 2.251 |
| 8 | 37.439 | 993.548 | 2.194 |
| 9 | 36.630 | 974.741 | 2.153 |
| 10 | 38.297 | 984.612 | 2.176 |
| 11 | 38.393 | 996.835 | 2.198 |
| 12 | 37.876 | 983.971 | 2.170 |

**Table 7.** Distribution of Environmental and Economic Results

| | Passenger Number | Carbon Foot Print (kg $CO_2e$) | Environmental Impact (mPts) | Environmental Cost (€) |
|---|---|---|---|---|
| International | 60361 | 2647493.06 | 67861168.79 | 149678.854 |
| Domestic | 89097 | 3047647.87 | 81182362.96 | 179363.495 |

## 4. Conclusion

The current paper introduces environmental and economic aspects of emitted exhaust gases from aircraft in the Isparta Süleyman Demirel Airport in the year of 2018. Within this context carbon foot print, environmental impact, and environmental cost are calculated. Thus real time data is obtained from the Ministry of Transport and Infrastructure of Republic of Turkey is used. The employed methodology is beneficial to determine the environmental impact and cost induced by environmental impact. Additionally, asserted methodology can be applied on different systems for environmental evaluation and/or optimization. According to the main findings of the study March month of the year is determined to be the peak point of the year regarding overall carbon foot print, environmental impact, and environmental cost values whereas April month of the year is found to be the peak point of the year regarding passenger based carbon foot print, environmental impact, and environmental cost values.

## Conflict of Interest

No conflict of interest was declared by the authors.

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