FORECASTING CARBON DIOXIDE EMISSIONS OF TURKEY'S INTERNATIONAL CIVIL AVIATION THROUGH 2030

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ABSTRACT

FORECASTING CARBON DIOXIDE EMISSIONS OF TURKEY'S INTERNATIONAL CIVIL AVIATION THROUGH 2030

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Nowadays, the aviation sector plays a vital role in the economic development of countries by connecting the continents. Air transportation is preferred more and more thanks to its advantages over the other transportation modes. After implementation of liberalization policies in Turkey, the aviation industry has shown a rapid development and the country has taken its place at the forefront in the world air transport. Due to the increasing demand for the aviation industry, inevitably CO_2 emissions of the sector increased rapidly. In spite of contributing to climate change in small percentages, the aviation industry is showing a much faster growth trend than other sources of emissions or industries.

In this study, Turkey's CO_2 emissions from international civil aviation activities are determined for the years between 2018 and 2030 by modelling Turkey's air passenger traffic demand under different scenarios. In air passenger traffic modeling, it is forecasted that air passenger traffic would reach 375,270 passenger-km according to the high scenario and 283,140 million passenger-km according to the low scenario. According to the high scenario the compound annual growth rate (CAGR) of Turkey is estimated to be 6.7% and in the low and medium scenarios, the CAGR is estimated as 4.6% and 5.8%, respectively.

By adding fuel efficiency assumptions to the estimated air passenger traffic data, future fuel demand and corresponding CO_2 emissions are calculated. As a result, Turkey's CO_2 emissions from international civil aviation activities in 2030 are expected to be between 20.62 and 33.33 Mtons. Even in the most optimistic case, CO_2 emissions of the international civil aviation of Turkey are tend to increase approximately 27% and under the highest scenario CO_2 emissions are expected to double in 2030 compared to 2017 levels.
The results of this study demonstrated that CO_2 emissions of the civil aviation sector continues to be one of the fastest growing source of the emissions in Turkey. Moreover, it is expected for civil aviation sector to take a large share of the Turkey's carbon budget in the near future.

Keywords: CO2 emissions, civil aviation, aviation emissions, international aviation, climate change

ÖZ

TÜRKİYE'NİN ULUSLARARASI SİVİL HAVACILIĞININ KARBONDİOKSİT EMİSYONLARININ 2030'A KADAR TAHMİN EDİLMESİ

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Havacılık sektörü günümüzde kıtaları birbirine bağlayarak ülkelerin ekonomik kalkınmasında hayati bir rol oynamaktadır. Hava yolu ulaşımı, dünyada ve ülkemizde diğer ulaşım sistemlerine göre sahip olduğu üstünlükler sayesinde her geçen gün daha fazla tercih edilmektedir. Havacılık alanında izlenen liberalleşme politikası sayesinde Türkiye'de havacılık sektörü hızla gelişim göstermiş ve ülkemiz hava ulaşımında dünyada ön sıralarda yerini almıştır. Havacılık endüstrisine olan talebin her geçen gün artması nedeni ile kaçınılmaz olarak sektörden kaynaklanan CO_2 emisyonlarında hızlı bir artış yaşanmıştır. Emisyon oranı ile iklim değişikliğine görece küçük oranlarda katkıda bulunmasına rağmen, havacılık endüstrisi diğer emisyon kaynaklarından veya sektörlerden çok daha hızlı bir büyüme eğilimi göstermektedir.

Bu çalışmada, Türkiye'nin 2018-2030 yılları arası için IPCC yöntemi kullanılarak uluslararası sivil havacılık faaliyetlerine bağlı olarak oluşan CO_2 emisyonları Türkiye'nin hava yolcu trafiği talebi modellenerek senaryolar bazında hesaplanmıştır. Hava yolcu trafik modellemesinde yüksek senaryoya göre 375,270 yolcu-km, en düşük senaryoya göre ise 283,140 milyon yolcu-km değerine ulaşılacağı hesaplanmıştır. En yüksek senaryoya göre Türkiye'nin yıllık bileşik büyüme oranı

%6.7 olurken, en düşük senaryo ve orta senaryoda yıllık bileşik büyüme oranı sırasıyla %4.6 ve %5.8 olarak tahmin edilmiştir.

Hesaplanan hava yolcu trafik verilerine, yakıt verimliliği varsayımları ilave edilerek gelecekteki yakıt ihtiyacı ve buna karşılık gelen CO_2 emisyonu hesaplanmıştır. Çalışma neticesinde Türkiye'nin 2030 yılı uluslararası havacılık kaynaklı CO_2 emisyonlarının 20.62 ile 33.33 Mton arasında olması beklenmektedir. En iyimser durumda bile, Türkiye'nin uluslararası sivil havacılığının CO_2 emisyonlarının yaklaşık %27 oranında artma eğiliminde olduğu ve en yüksek senaryoda CO_2 emisyonlarının 2030'da 2017'ye kıyasla iki katına çıkması beklenmektedir.

Bu çalışmanın sonuçları, sivil havacılık sektörünün CO_2 emisyonlarının, Türkiye'de emisyonların en hızlı büyüyen kaynaklarından biri olmaya devam ettiğini göstermiştir. Ayrıca, sivil havacılık sektörünün yakın gelecekte Türkiye'nin karbon bütçesinden büyük bir pay alması beklenmektedir.

Anahtar Kelimeler: CO2 emisyonu, sivil havacılık, havacılık emisyonları, uluslararası havacılık, iklim değişikliği

To my beloved Family

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ABBREVIATIONS

ASK	Available Seat Kilometers
ATAG	Air Transport Action Group
ATK	Available Ton Kilometers
CAGR	Compound Annual Growth Rate
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting And Reduction Scheme For International Aviation
DGCA	Directorate General of Civil Aviation
FTK	Freight-Tons Kilometers
GDP	Gross Domestic Product
GHG	Greenhouse Gas
H_2O	Water Vapor
ICAO	International Civil Aviation Organization
IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
LTO	Landing And Take-Off
MAPE	Mean Absolute Percentage Error
Mton	Million Tons
mW/m^2	Milliwatt Per Square Meter
NMVOCs	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
OECD	Economic Co-operation and Development
PwC	PricewaterhouseCoopers
RMSE	Root Mean Square Error
RPK	Revenue Passenger Kilometer
RTK	Revenue Ton Kilometer
Sc	Scenario
SKO	Seat Kilometers Offered
SO_x	Sulfur Oxides
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USD	United State Dollars

CHAPTER 1

INTRODUCTION

1.1. Background Information

In 1950s civil aviation was an underdeveloped industry which accounts for a small portion of the transportation sector. However today, aviation sector plays a vital role in the countries' economic development by connecting the continents for business, tourism, trade, defense, and humanitarian purposes. According to the report published by Air Transport Action Group (ATAG), in 2016 aviation industry contributed 2.7 trillion USD (direct, indirect, induced, and tourism catalytic) to the global gross domestic product (GDP) which is equal to the 3.6% of the world's GDP. The sector conducted 120 thousand flights and carried 12 million passengers every day in 2018 (ATAG, 2018).

The aviation sector experienced rapid growth since 1980s. According to latest annual reports of the International Civil Aviation Organization (ICAO), number of passengers was 0.6 billion in 1980 and then increased to 4.1 billion in 2017. World total revenue traffic including international and domestic services exceeded 945 billion revenue ton kilometers[1] (RTK) in 2017, and increased at an average rate of 6 percent per annum over the last five years. In 2017, total passenger traffic reached to 7.7 trillion revenue passenger kilometers[2] (RPK). In the same year, operating revenues of airlines of the ICAO member states reached to 757 billion USD, which is around 150 percent above 2000 levels (ICAO, 2000-2017; ICAO, 2017).

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[1] RTK (ton-km): Measure of volume of load transported in aviation industry equal to one ton of revenue load (passenger and/or cargo) transported one kilometer.
[2] RPK (passenger-km): Measure of the volume of passengers in aviation industry equal to one revenue passenger transported one kilometer.

Moreover, against uncertainties, the report published by Boeing estimates that the passenger traffic will rise over 5% globally and over the next 20 years this growth trend is expected to be continued (Boeing, 2013).

In Turkey before 2000s, the aviation sector was dominated by Turkish Airlines. After the implementation of liberalization policies and providing incentives, private companies started to enter to the market so that Turkish aviation industry started to develop and enlarge (Gerede, 2010). After 2003, stability gained in the sector and the measures taken in that field kicked in, so that aviation industry became a significant actor for Turkey's economic development. According to Turkey's Action Plan for Emission Reduction submitted to ICAO, the number of people employed by aviation industry is raised to 65 thousand to 196 thousand between 2003 and 2017 (SHGM, 2018). Today Turkey has 11 commercial airlines and 57 airports with 91.34% accessibility rate (ATAG, 2018; SHGM, 2018). The list of commercial airlines and airports in Turkey are provided below in Table 1.1 and Figure 1.1.

Table 1.1 List of commercial airlines in Turkey as of 2018 (SHGM, 2018)

Name of the Airline
ACT Airlines
Atlas Global Airlines
Corendon Airlines
Freebird Airlines
MNG Airlines
Onur Airlines
Pegasus Airlines
SunExpress Airlines
Tailwind Airlines
Turkish Airlines
ULS Airlines

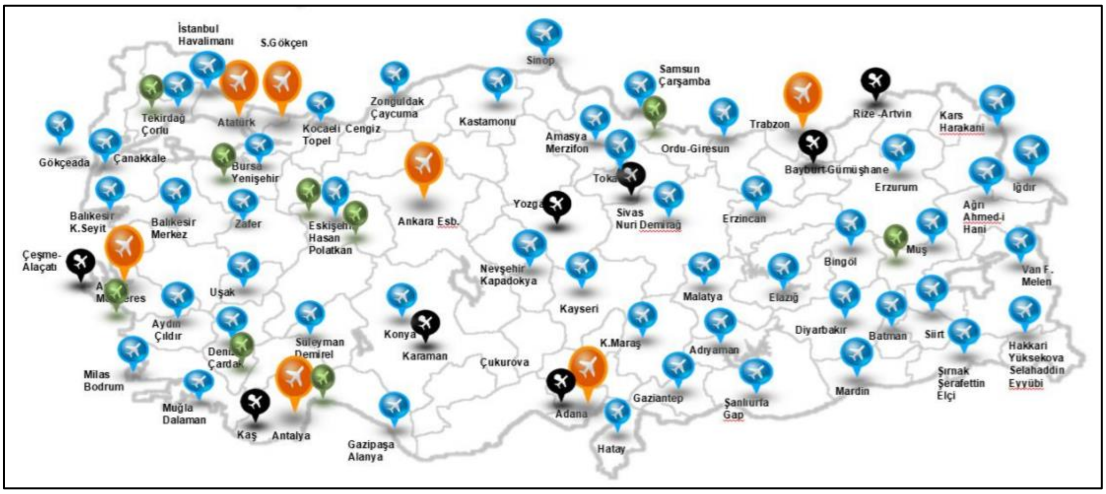

Figure 1.1 Distribution of airports in Turkey as of 2018 (SHGM, 2018)

In Figure 1.1 orange label represents the major airports, black label represents the airports under construction, and blue label represents the other airports open to commercial air traffic in Turkey. On the other hand the green label shows the landing strips in Turkey.

Table 1.2 shows the development of international aviation activities of Turkey. In the annual report of Directorate General of Civil Aviation (DGCA) of Turkey, it is reported that the number of airlines performing international flights were only two in 2003 and it has increased to five in 2017. The number of countries that Turkey has bilateral air transport agreements increased from 50 to 124 countries in which 318 different destinations can be flown. The figure below well represents the volume of the increase in the number of the destinations and shows the name of the airlines performing international flights in 2003 and 2018.

Table 1.2 Development of international aviation in Turkey (SHGM, 2018)

	2003	2017
Number of airline operators	2	5
Number of countries flown	50	124
Number of destination flown	60	318

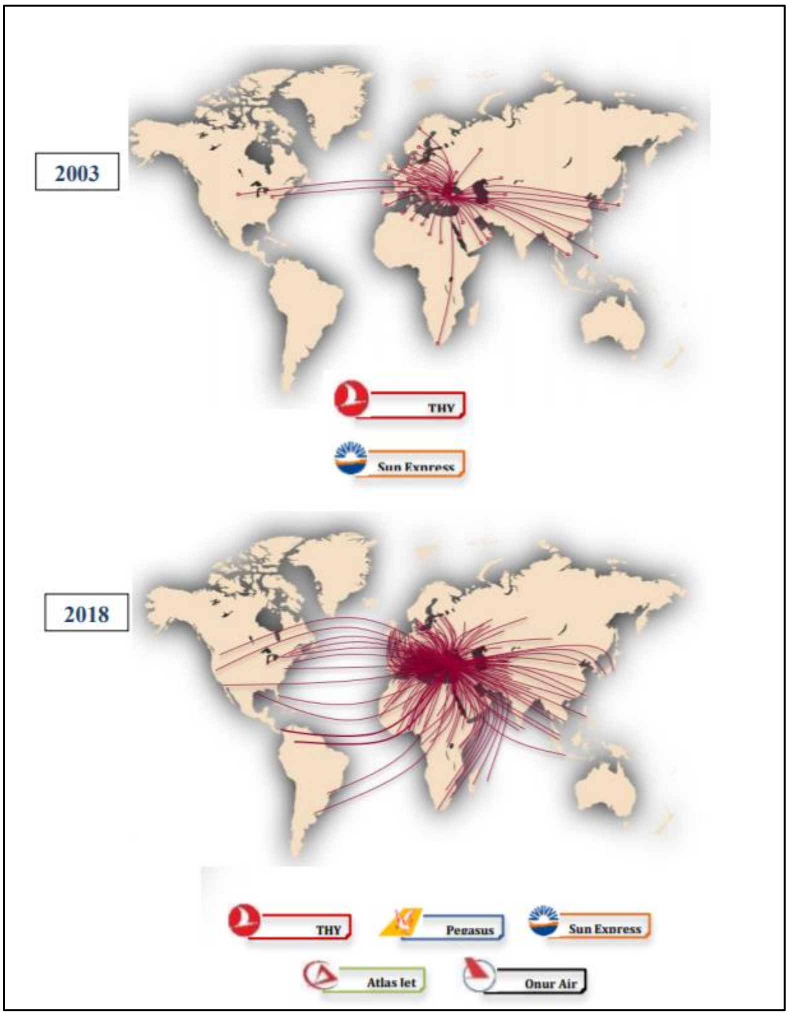

Figure 1.2 International flight destinations in 2003 and 2017 from Turkey (SHGM, 2018)

According to the 2017 annual report of the ICAO, Turkey ranks 11th in the world in terms of the total revenue traffic, including passenger and cargo. Total RTK of Turkey reached 27.4 billion-ton kilometers and increased at an average rate of 16 percent per annum over the last five years which is nearly three times above the world average. In 2017, total passenger traffic of Turkey is reported as 183.4 billion revenue passenger kilometers, of which 147.7 billion revenue passenger kilometers is international. With this performance Turkey ranked 12th in the world in terms of total and 9th in the world in terms of international passenger traffic (ICAO, 2017). Figure 1.3 shows the Turkey's rankings in world in 2017.

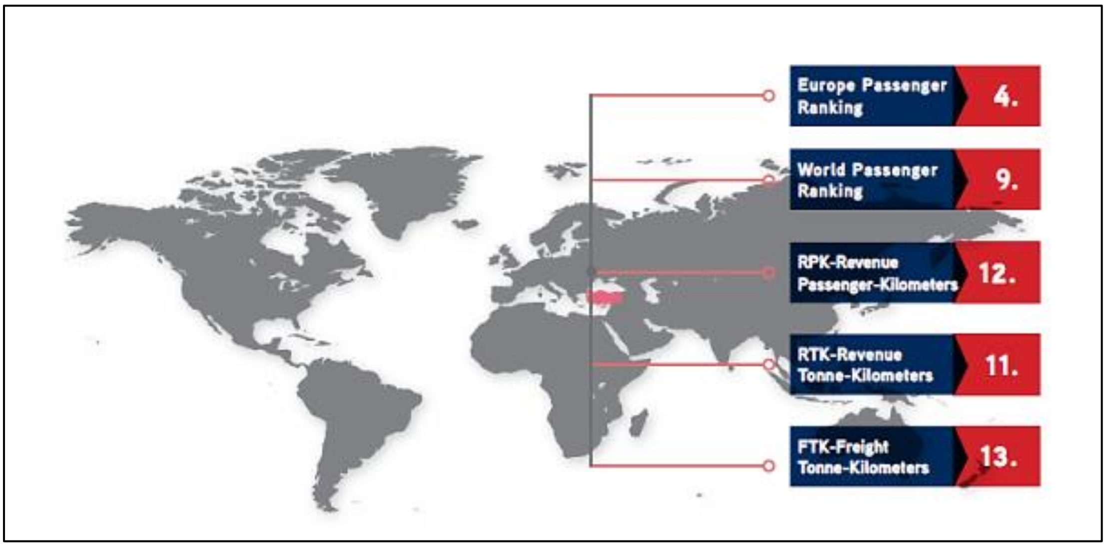

Figure 1.3 Turkey's ranking in the world in 2017 (SHGM, 2018)

In order to be able to compare the growth of Turkish civil aviation with other leading countries in aviation Figure 1.4 and Figure 1.5 show the change in the ranking of countries in terms of RTK and RPK progress with respect to years where each RTK and RPK values and corresponding rankings are obtained from the annual reports of the ICAO published between 2000 and 2017 (ICAO, 2000-2017).

In terms of both RTK and RPK, United States and China are the two leading countries. However, in years rankings of other countries are chancing depending on the air transport performance. For example in 2009, Turkey was 20th in the world in terms of RTK. Over the years country increased her performance and took the 9th place in 2017. On the other hand, France's performance went downward and her ranking changed 6th to 8th in 2009 and 2017 respectively.

Likewise RTK performance, Turkey's RPK ranking demonstrated upward trend between 2009 and 2015. In 2016, air transport activities decreased due to international relations of country and the ranking fell back in 2016. Then, in 2017 Turkey ranked as the 12th in the world in terms of RPK.

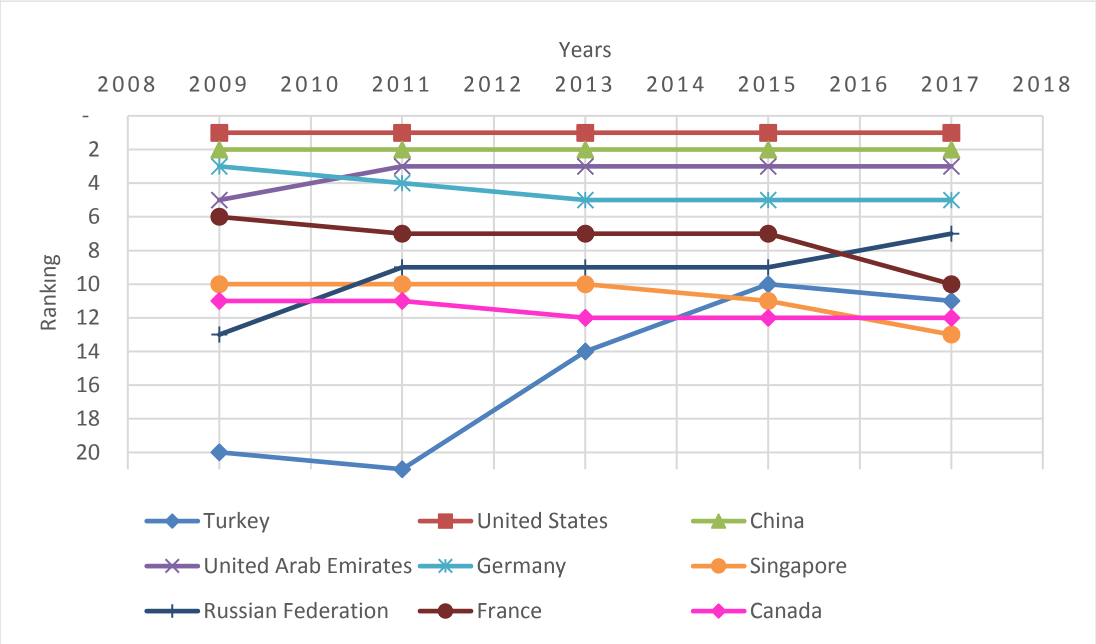

Figure 1.4 Changes in the rankings of countries in terms of RTK. Adapted from (ICAO, 2001)

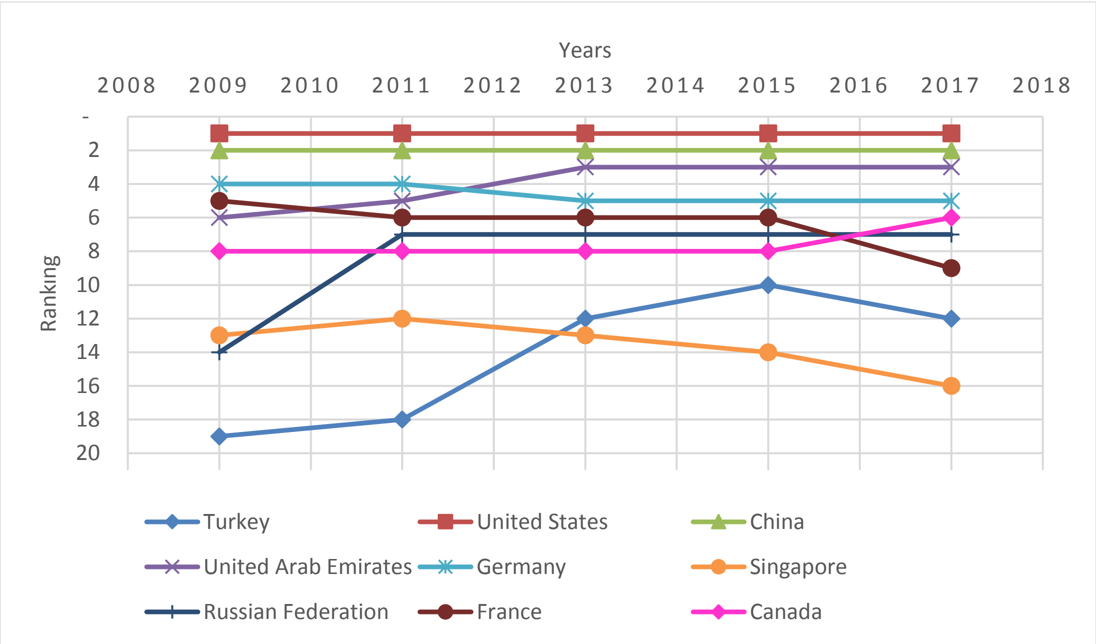

Figure 1.5 changes in the rankings of countries in terms of RPK. Adapted from (ICAO, 2001)

Due to geographical position, Turkey is included in the Europe region in these forecast reports. However, unlike in Turkey, in Europe most of the countries' aviation sector is pretty mature. The Figure 1.6 shows the number of passengers carried by some aviation leading countries in Europe and Turkey between 1970 and 2016 (World Bank, 2019). As it can be seen from the figure, European countries experienced higher growth rates between 1970 and 2000. However in the same time interval Turkey's aviation sector was not growing evenly. On the contrary, in last couple years, especially after 2000s, Turkey demonstrated a tremendous growth performance where the growth performance of the other European countries except Germany is stabilized. In other words, after 2000s annual air passenger traffic growth rates of European countries are well below the Turkey's growth rate. So, the forecast results prepared for the Europe region including Turkey does not fairly reflect the Turkey's situation.

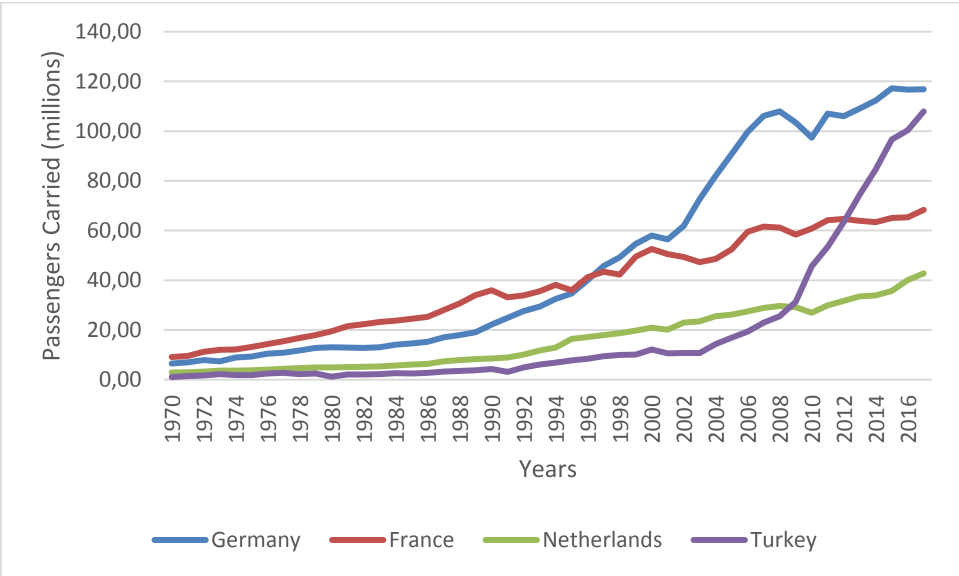

Figure 1.6 Air transport sector development of different countries (World Bank, 2019)

As the world's and Turkey's aviation performances continue to exhibit rapid growth, unavoidably an important increase is being observed in the greenhouse gas (GHG) emissions due to jet fuel burn in the engines. Aircrafts emit a variety of GHG but due to stable nature and scientific knowledge the major concern is on the carbon dioxide

(CO_2) emissions. Currently emissions related to aviation activities contributes around 2-3% to the total global anthropogenic CO_2 emissions (Edwards, Dixon-Hardy, & Wadud, 2016).

According to the National Inventory Report of Turkey, Turkey's total emissions are calculated as 526.3 Mton CO_2 equivalent in 2017. In the same year, emissions originating from international aviation is reported as 14 Mton CO_2 equivalent which means Turkey's international aviation contributing around 2.6% to the Turkey's total emissions (Turkish Statistical Institute, 2019).

In spite of contributing to climate change in small percentages, the aviation industry is showing much faster growth trend than other sources of emissions or industry (Mayor & Tol, 2009). On the other hand, international civil aviation activities are responsible from over 60% of total aviation emissions. Especially, emissions originating from international civil aviation activities are showing much faster growth trend compared to domestic activities (Macintosh & Wallace, 2008).

In 1999, ICAO requested a forecast report from Intergovernmental Panel on Climate Change (IPCC) regarding to CO_2 emission from the civil aviation activities. Upon the request IPCC found that CO_2 emissions related to aviation activities could increase between 60% and over 1000% between 1992 and 2050 (IPCC, 1999).

In 2009, ICAO conducted its own forecasts, the results of the study showed that by 2050 CO_2 emissions from the aviation could grow around 300-500% compared to 2005 levels, while another study conducted by a group of researchers found out that along with the growth of the sector, the emissions related to the aviation activities are likely to increase three times between 2000 and 2050 (Berghof, et al., 2005; Horton, 2006; ICAO, 2009).

1.2. Problem Definition

As stated earlier, in today's world due to tourism, trade, defense, business, and humanitarian purposes air transport is essential. Civil aviation activities in Turkey are increasing sharply and country experiences tremendous growth rates, three times the world average, in terms of air traffic. In parallel with the increasing air traffic, CO_2 emissions are also increasing rapidly and causing adverse effects on the climate change.

Secondly, in Turkey there are a few studies conducted to forecast the air traffic demand, fuel demand, and thus CO_2 emissions associated with the civil aviation activities. The existing studies focus on development of domestic air transportation, jet fuel and bio-fuel demand combined or airport level emission calculation. On the other hand, industry representatives and several organizations prepare forecast reports, publish them on their web-site and update them annually. However, these reports represent regional based air traffic forecast and route-based air traffic developments. In these reports, due to geographical position, Turkey is included in the Europe region in which most of the countries' aviation sector is pretty mature. Although being a part of Europe, likewise the economy, Turkey's civil aviation growth trend does not follow the European growth trend. Turkey is experiencing more aggressive growth trend than Europe. So, the growth rates published for Europe in these reports do not very well reflect the growth trend of Turkey.

Thirdly, since 2012, across the world, the issue of controlling the international CO_2 emissions of the sector became a significant topic for policy makers. In the last few years, various control mechanisms have been established and the industry became one of the integral parts of international aviation environmental policies. For this reason, in Turkey, there is a need for a guiding study to be used in decision-making mechanisms in order to ensure sustainable growth of the sector by following environmental protection measures taken locally or regionally without restricting aviation activities.

1.3. Objective of the Study

The principle objective of this study is to estimate CO_2 emissions associated with the international civil aviation activities of Turkey through 2030 based on econometric regression analysis. Up to date, forecast studies regarding to CO_2 emissions of the international civil aviation activities of Turkey are very limited. So, this is the first study that estimates the growth of RPK for a fast growing country in aviation sector and predicts the corresponding future CO_2 emissions.

Thus, in this study it is aimed to:

- Develop representative and reliable regression model that can estimate air passenger traffic in terms of RPK ,
- Estimate 2018-2030 RPK values with the use of key influential indicators (economic, demographic and social variables) by using the developed model under three different scenarios,
- Estimate fuel demand between 2018 and 2030 based on fuel intensity approach corresponding to the air passenger traffic results,
- Estimate future CO_2 emissions originating from international civil aviation activities of Turkey through 2030 by using IPCC emission conversion factors based on the fuel demand results.

1.4. Scope of the Study

In terms of the GHG emission reporting and climate policy, civil aviation is divided into two components as domestic aviation and international aviation. According to the IPCC Guidelines for National Greenhouse Gas Inventories domestic aviation activities are defined as the flights that departs and arrives in the same country. These inventories are prepared for the reporting purposes under the United Nations Framework Convention on Climate Change (UNFCCC). The same guidelines define the international flights as the flights departed from one country and arrive in a different country (IPCC, 2006). Whereas ICAO which is the specialized agency of the United Nations (UN) on aviation, defines the international flights as the take-off at an aerodrome of a State or its territories, and landing at an aerodrome of another State or its territories (ICAO , 2018).

Under UNFCCC and Kyoto regime, when states are reporting their total national emissions, they are required to include emissions resulted from domestic aviation activities. On the contrary, international aviation emissions are excluded from the national inventories of the countries and can be attached to the inventory as a memo document (Macintosh & Wallace, 2008).

Moreover, the responsibility of the international aviation is given to ICAO with Article 2(2) of the Kyoto Protocol (United Nations, 1998). The rationale behind the classification of the aviation emissions as domestic and international is related to the UNFCCC greenhouse gas accounting mechanism and international law. Based on international law, each state has complete and exclusive sovereignty on their airspace above the state's territory. For the activities apart from the boundaries, states are subjected to law related to Chicago Convention, whereby ICAO is established (Macintosh & Wallace, 2008).

Due to this differentiation by law and data availability only CO_2 emissions associated with commercial air transport service performed at international level are forecasted in the context of this thesis where international flights are defined as the flights that depart in one state and arrive in a different state. Once the scope has been determined, only international data is used in future emission estimation studies.

1.5. Structure of the Study

This thesis is organized as follows. In Chapter 2 of this thesis, background information is provided. Firstly, impact of aviation on climate change is summarized and the reason behind studying only the CO_2 emissions is explained, then existing emission calculation methods for aviation related activities are summarized.

In Chapter 3, previous studies regarding to the topic of this thesis is reviewed from the literature. Especially, studies containing information on air traffic demand forecasting, fuel demand forecasting, and calculation of CO_2 emissions are reviewed.

In Chapter 4, methodology used under this thesis explained by showing the model development and scenario application stages. Also selected CO_2 emission calculation methodology is summarized. In addition to the methodology, the data gathered in this thesis is presented under this chapter. Firstly, data section involves historical data utilized in the development of the air passenger traffic forecast model which includes international RPK data, real GDP data, population data and propensity data. Secondly, historical international fuel consumption data of Turkey and fuel specific emission factor data that are needed to calculate CO_2 emissions are given in the data section. After providing historical data, future estimates of each parameters used in the regression model is shown. Future estimates of each parameter are presented under three different scenarios correspondingly which are namely medium, low and high scenarios. Lastly, under Chapter 4, annual fuel intensity improvement assumptions under three scenarios are presented.

In Chapter 5, the results of the regression analysis and forecast study are provided. Firstly, the air passenger traffic forecast results are shown according to each scenario. Then the fuel demand forecast results obtained according to the air passenger traffic results are provided. After obtaining the fuel demand forecast results, the corresponding CO_2 emissions of each scenario are presented.

Chapter 6 presents the conclusion and recommendation for future works.

CHAPTER 2

OVERVIEW ON AVIATION EMISSIONS

2.1. Impact of Aviation on Climate Change

Currently emission related to aviation activities contributes around 2-3% to the total global anthropogenic CO_2 emissions (Edwards, Dixon-Hardy, & Wadud, 2016). In spite of contributing to climate change in small percentages, the aviation is showing a growth trend much faster than other sources of emissions (Mayor & Tol, 2009).

Although aviation is not currently among the major contributing sectors to the climate change in terms of emissions, the trajectory studies demonstrates that the industry could become an important contributor over the coming years. Due to the rapid growth of the sector, many concerns raised on the impact of the sector related emissions on the climate system. Hence international civil aviation activities became the major concern for the discussions about aviation and the climate change. The reason behind taking only the international activities to the focus of the discussion was that the international activities are responsible over 60% of total aviation emissions. Moreover, the emissions originated from international activities show much faster growth compared to domestic activities (Macintosh & Wallace, 2008).

Along with the rapid growth experienced in the air transport and the future growth expectations, fuel consumption and adverse impacts of the sector on environment are expected to increase. Emissions from the aviation originates from the combustion of aviation fuels. Aviation fuels can be in the forms of jet fuel (Jet A, Jet A-1, kerosene), kerosene-gasoline mixture (Jet B), aviation gasoline (avgas), and bio kerosene (Oiltanking, 2019). For commercial aviation Jet A and Jet A-1 are the ones most commonly used fuels, so they are produced with a standardized international requirement (Skybrary, 2018).

When jet fuel is burned in the aircraft engines, the aircraft emission formed contains 70% CO_2, less than 30% water vapor (H_2O), and less than 1% each of nitrogen oxides (NO_x), carbon monoxide (CO), sulfur oxides (SO_x), non-methane volatile organic compounds (NMVOCs), particulates, and other trace components (IPCC, 1999). Methane (CH_4) also can be emitted by gas turbines when the aircraft is in the idle position or in older technologies. However recent data shows that nearly no CH_4 is emitted by new aircraft technologies (IPCC, 1999).

These emissions from aircraft have a crucial impact on climate systems since they affect the radiative balance of the atmosphere under different conditions and mechanisms (Dessens, 2014). IPCC defines the radiative forcing as the effect of a substance on the earth's atmosphere's energy balance. In more technical words, it is the measure of change in the net irradiance at the boundary layer between the troposphere and stratosphere (i.e. tropopause) represented by watts per square meter (IPCC, 2001). Table 2.1 summarizes the atmospheric impacts of the emissions and their radiative forcing (Sausen, et al., 2000).

Table 2.1 Atmospheric impacts of the emissions and their radiative forcing (Sausen, et al., 2000).

Emission	**Comment**	**Radiative forcing (mW/m^2)**	**Scientific understanding**
CO_2	Long-lived GHG and has warming effect	+25	Well understood
NO_x	NO_x has both warming and cooling effect. Warming due to formation of ozone (O_3) in troposphere, cooling due to reactions with NO_x and removal of CH_4 from atmosphere.	+22 -10	Fairly understood Fairly understood
H_2O Contrails Cirrus	H_2O accumulates in the lower stratosphere and by trapping infrared radiation causes warming effect. Creates contrails acting like clouds and traps heat.	+2 +10 +30	Fairly understood Fairly understood

Emission	Comment	Radiative forcing (mW/m^2)	Scientific understanding
	Contrails can create cirrus clouds causes warming effect.		Poorly understood
SO_x	SO_x leads formation of sulphur aerosols reflecting radiation and causes cooling effect. Can change the cloud formation mechanism as an indirect effect.	-3.5	Fairly understood
Soot	Soot traps and radiates the heat, has warming effect.	+2.5	Fairly understood
Total		+48	

In the table positive sign indicates that the particular emission has warming impact and negative sign indicates the cooling impact. Although aviation is not among the main contributor to the climate change currently, aviation related emissions still has to be controlled and incorporated into policies (Macintosh & Wallace, 2008). As can be seen from the table above, the understanding level of the emissions is different from each other. The main reason behind that is the warming effect of the emissions other than CO_2, can differ significantly depending on the conditions and altitudes in which they are emitted. Moreover the processes and the reactions caused by non-CO_2 emissions in different altitudes are not well understood (Timperley, 2017). Although it is known that they have a vital impact on the climate change, uncertainty in the how to account for non-CO_2 emissions creates technical difficulty for policy makers to tackle with the non-CO_2 emissions (Macintosh & Wallace, 2008).

On the other hand, impact of CO_2, known as the most important GHG, does not differ with respect to altitude and there is no additional impact is observed along the different levels. Simply the impact of the CO_2 is same on all levels. Thanks to stable property of the CO_2, the scientific understanding level of this gas is better than other GHGs emitted by aircrafts. This situation makes the things easier so that policy makers can easily establish control mechanism and regulate the CO_2 emissions (ATAG, 2019). Due to that reason, the control mechanisms or policies for international aviation so far only focus on CO_2 emissions. Therefore, within this thesis only CO_2 emissions will be forecasted and data required to calculate CO_2 emissions will be demonstrated.

2.2. CO_2 Emission Calculations

In this chapter, the emission calculation methodologies available for use is reviewed. Firstly IPCC methodology is described, and subsequently ICAO approach is explained.

Mainly, emissions are originating from the jet fuel and aviation gasoline that are combusted in the aircraft engines. Since this thesis focuses solely on the CO_2 emissions, only calculation of this GHG will be considered in this section.

In chapter 3 of the IPCC Guidelines for National Greenhouse Gas Inventories published in 2006, three methodological tiers are introduced for the calculation of CO_2 emissions from the civil aviation activities. The document provides three different approaches for the users according to fuel type, availability of the data and relative importance of the emissions. Tier 2 and 3 gives more accurate results compared to Tier 1 since they use bottom-up approach that requires more factors like fleet information, aircraft type, engine type, efficiency of each aircraft type etc. (IPCC, 2006).

Tier 1 method is the simplest method and requires the aggregated fuel consumption data, type of fuel used and the fuel specific emission factor. To determine the emission factors for different fuel types, the document also provides CO_2 emission factors for aviation gasoline and jet kerosene separately. The document suggests the use of the national emission factor based on the fuel carbon content, however in the absence of this data CO_2 emissions are calculated with the full carbon content of the fuel (IPCC, 2006). Basically IPCC Tier 1 Calculation Method uses the formula below;

$$\textit{Emissions(ton } CO_2\textit{)} = \textit{Fuel Consumption(ton)} * \textit{Emission Factor(ton } CO_2\textit{/ton)} \quad (1)$$

On the other hand IPCC Tier 2 method is only valid for the situations that jet fuel use in jet aircraft engines. Moreover Tier 2 made a distinction between the flight phases since the fuel consumption differs at different flight stages. Figure 2.1 represents the phases of a flight. The activities below the 3000 feet is named as Landing and Take-off (LTO) cycle and above 3000 feet (i.e. 914.4 meters) the flight stage is named as cruise phase.

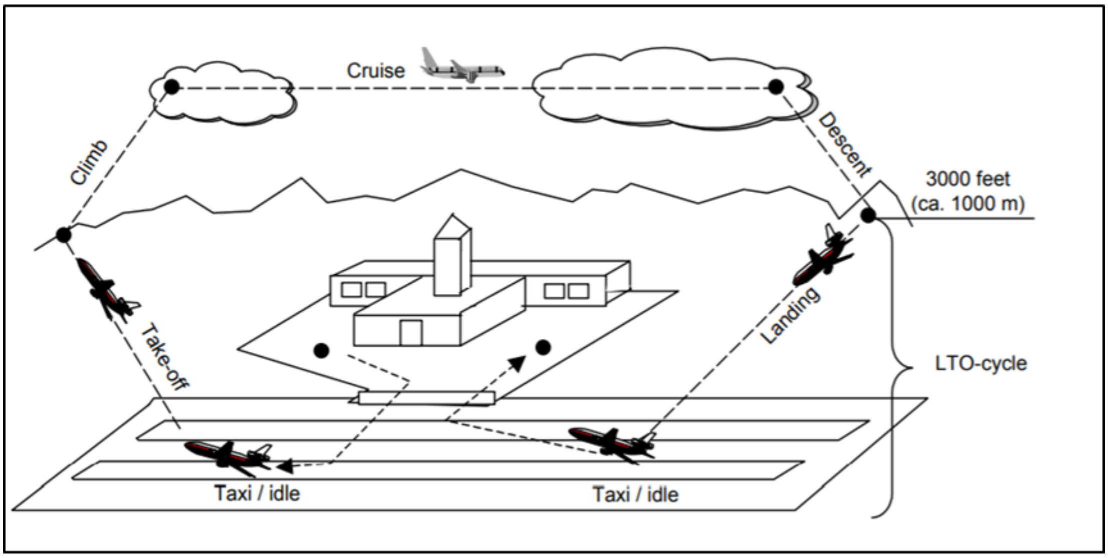

Figure 2.1 Flight stages

In tier 2, total emissions are calculated by the use of following equations;

Total Emissions(ton CO_2) = LTO Emissions(ton CO_2) + Cruise phase Emissions(ton CO_2) (2)

where;

*LTO Emissions(ton CO_2)= Number of LTOs(#) * Emission Factor for LTO(ton/# of LTO)* (3)

Cruise Phase Emissions(ton CO_2) = (Total Fuel Cons.(ton) – LTO Fuel Cons.(ton)) × Emission Factor at Cruise phase(ton CO_2/ton) (4)

*LTO Fuel Consumption(ton)= Number of LTOs(#) * Fuel Consumption per LTO(ton/# of LTO)* (5)

In order to be able to use the Tier 2 method, the statistical data about the aggregated number of LTOs or number of LTOs per aircraft type, default emissions factors or fuel use factors (can be average or per aircraft type) must be available. The document provides two tables containing a list of factors for fuel use and emission factors for different aircraft types for LTO cycles and aggregate emission factors per LTO cycle. For the calculation of cruise phase emissions either national or default emission factors are required (IPCC, 2006).

In Tier 3 calculation, guidelines recommends Tier 3a method and Tier 3b method which are both based on the actual flight data. Likewise Tier 2, Tier 3a also differentiates the emissions generated at the different stages of the flight. In addition to this, in Tier 3a method, fuel consumption with respect to flight distance is taken into account since fuel consumption data varies based on the flight distance. On short distances the aircraft consumes higher level of fuel compared to longer routes since for the LTO cycle aircrafts use higher quantity of fuel per distance compared to the cruise phase. In Tier 3a EMEP/CORINAIR Emission inventory guide book published electronically by European Environmental Agency is used for the emission calculations (European Environment Agency, 2007). The guidebook provides tables regarding to emissions per flight distances and revised periodically. Tier 3b method utilizes full trajectory of each flight segment and engine specific aerodynamic performance data. In order to be able to use Tier 3b methods, complex computer based modelling programs capable of running with numerous variables are required (IPCC, 2006).

On the other hand, ICAO uses fuel conversion factors which are in line with the IPCC Guidelines. However in order to sustain the simplicity ICAO uses two digit conversion factors which are summarized in Table 2.2.

Table 2.2 ICAO fuel conversion factors (ICAO, 2018)

Fuel Type	ICAO Conversion Factor (kg CO_2/kg fuel)
Jet-A / Jet-A1	3.16
AvGas / Jet B	3.10

2.3. Closing Remarks

In this Chapter, impacts of aviation on climate change is explained by providing detailed information on the atmospheric impacts of the each emissions emitted and the reason behind taking the CO_2 into the scope of this thesis is explained. Also, different methods for CO_2 emission calculations are introduced and summarized.

CHAPTER 3

LITERATURE REVIEW

3.1. Air Traffic Forecast Studies

In this section, the methods exist in literature regarding to air traffic forecasting and the factors that should be included into the forecast studies are summarized.

For the estimation of air traffic demand several methods are available for use. ICAO document called Manual on Air Traffic Forecasting introduces three broad methods which are quantitative or mathematical, qualitative or judgmental and decision analysis (i.e. combination of the first two methods). According to the document in the quantitative method, forecasting methodology starts with set of historical data and then a model is developed with certain rules. On the other hand, in the qualitative method, generally set of historical data is not available or applicable so that for the prediction judgement experience is needed. Decision analysis combines both quantitative and qualitative analysis methods. In decision analysis judgement experience of analyst is reflected to forecasts then is it combined with mathematical methods. Generally, in air traffic forecasting, historical traffic data is measured in terms of passengers or RPK and tons of freight or freight-tons kilometers (FTK) (ICAO, 2006).

As illustrated on Figure 3.1 quantitative method can be divided into two sub-methods as time series analysis and causal methods. In quantitative method trend projections, decomposition methods, and regression analysis are the most widely used techniques (ICAO, 2006).

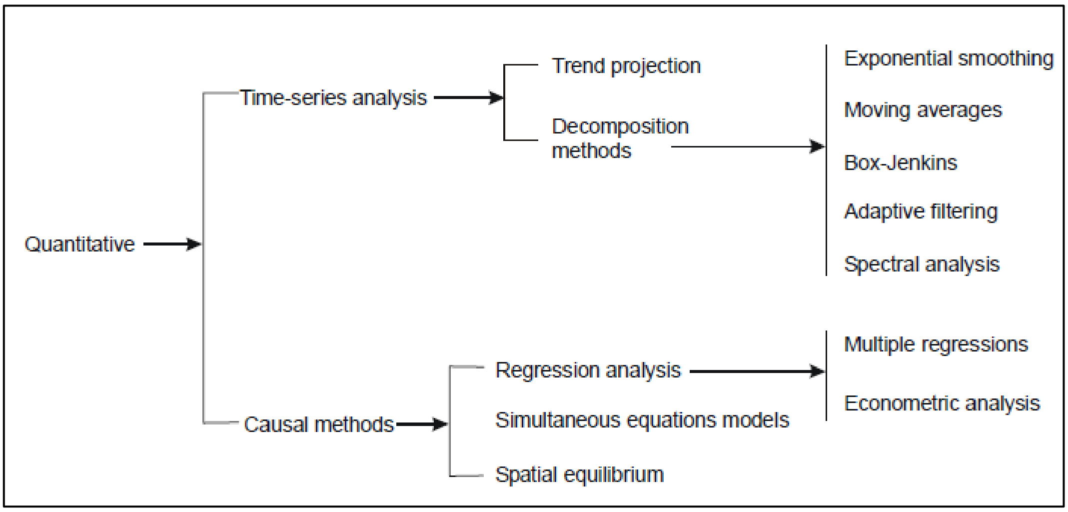

Figure 3.1 Quantitative forecasting techniques (ICAO, 2006)

The results obtained by the time-series analysis methods heavily rely on the continuation of the historical pattern assumption and in order to be able to use this method availability of historical data on air traffic activity is essential. In the context of trend projection, medium-term or long-term forecast can be conducted. While developing a forecast by trend projection short-term fluctuations occurred in the air traffic trend are eliminated, since the methodology assumes historical development of the traffic will continue in the future as in the past. The most important indicator of the selection of this method is the stability of the air traffic activity in the past and the confidence of the analyst that the assumption of continuing trend is applicable. Decomposition method relies on the determinations of the seasonal or cyclical factors for the estimation of the trend. So that, in that method analyst must have historical data and strong seasonality or cyclical patterns exist in the historical data (ICAO, 2006).

Causal method is generally giving more reliable results when it is applied on short term. The method relies on the extrapolation of past growth trends. Among the causal methods regression analysis is the most widely used method in the civil aviation demand forecast studies. In regression analysis, in addition to historical data other variables that have a causal relationship with the historical data is taken into account.

For example, the econometric analysis is a multiple regression analysis with a price-income structure. In order to conduct econometric analysis firstly a regression equation model that postulates a causal relationship between a dependent variable and one or more explanatory variables must be established (ICAO, 2006).
ICAO uses econometric analysis for its forecast by taking into account world GDP as a measure of economic activity and airline yields. Airline yields are expressed as RPK used as a term for weighted average airline fares. The world GDP which is also the most common parameter available for economic index is incorporated into the ICAO's model because it represents impact of economic, demographic and income factors (ICAO, 2006).
Moreover, ICAO conducted a study analyzing the growth of historical RPK data for world airline scheduled traffic from 1960-2000 and compare it with the growth of world GDP. The study showed that, corresponding GDP for the ten-year periods had grown in parallel with air traffic data. In the ICAO forecasting model once the GDP and yield values have been determined for each of the years of the forecast time frame, they are inserted into the model to estimate the air traffic data for future (ICAO, 2006). Based on this methodology, ICAO publishes the results in terms of compound annual growth rate in RPK or FTK for the forecast time horizon. In the ICAO Long Term Traffic Forecasts Report published in 2016 it is estimated that that global passenger traffic will grow at 4.6 per cent annually until 2032 (ICAO, 2016).
ICAO estimates and publishes air traffic forecast on global or regional wide not on the country wide. So, more studies conducted on country or regional level that are using regression model are investigated in literature and the independent variables employed in the models are reviewed in this thesis.
A study conducted by Sivrikaya and Tunç (2013), established a semi logarithmic regression model to determine the factor affecting the air travel demand for domestic market by city pair level in Turkey. In the study, they utilized the 2011 air passenger data and tested the accuracy of model with the 2010 data. According to the results; urban population, distance and the number of beds in tourism facility are determined as the significant macroeconomic factors that have positive impact on the air transport

demand in Turkey. On the other hand; average ticket price, travel time and transit (availability of direct flights) variables included into the model and found as variables have negative impact on air passenger demand (Sivrikaya & Tunç, 2013).

Another study analyzed the socio-economic and demographic indicators that are affecting the growth of civil aviation. In the paper, influential factors are categorized in three main titles which are social, economic and demographic factors. And their push and pull attitude is investigated where push factors are defined as internal factors positively supporting the industry, whereas pull factors are external factors that are dependent on consumer behavior and negatively affects the growth of the civil aviation. In the results, it is found that performance indicators which are propensity to travel, urbanization levels, growing middle classes, key economic indicators, level of liberalization and airlines' business model have pulling effect on air travel growth which means these factors are supporting the growth of the civil aviation. On the other hand, the factors environmental awareness, working age population and external shocks are determined as the factors influencing the growth of civil aviation in a negative way (Adderpalli, Pagalday, Salonitis, & Roy, 2018).

Some examples of other studies employing regression model analysis for air passenger forecasts are summarized in Table 3.1 and the variables included into the regression models are identified.

Table 3.1 Summary of studies in literature employing regression analysis for air transport forecast

Research Name	Method	Independent Variables	Scope	Reference
An Econometric Analysis of International Air Travel Demand in Saudi Arabia	Stepwise linear regression with aggregated data	✓ Total expenditures ✓ **Population size**	Domestic	(Abed, Ba-Fail, & Jasimuddin, 2001)
Factors Influencing European Passenger Demand for Air Transport	Regression analysis	✓ **Gross Domestic Product per capita (GDP),** ✓ **Urban Population,** ✓ Geographical location of a country, ✓ **Number of air trips per capita per country** ✓ Degree of education	Regional	(Cook, Kluge, Paul, & Cristobal , 2017)
Demand for Air Transport in Nigeria	Multiple regression method with aggregated data	✓ Index of Agricultural Production, ✓ Index of Manufacturing Production, ✓ **Gross Domestic Product**, ✓ Inflationary Rate ✓ Consumer Price Index	Domestic	(Aderamo, 2010)

3.2. Fuel Demand Forecast Studies

In this chapter, the studies in literature that are about jet fuel demand forecasting are examined and summarized.

Firstly, according to the literature search, fuel consumption of aircraft is affected by several factors. Some of these factors can be controlled by aircraft operators, some of them can be regulated by civil aviation authorities, some of them can be reduced by effective airport management, and some are really hard to control since they are only subjected to the weather conditions. The main factors affecting the amount of fuel consumed by aircraft in a single flight can be listed as follows;

- Aircraft type,
- Engine type,
- Flight route and distance,
- Flight altitude,
- Weight of the aircraft,
- Weight carried by the aircraft,
- Operational methods,
- Weather,
- Efficiency enhancements (UK CAA, 2017).

Since it is hard to include and predict all these factors in a single model, jet fuel demand cannot be modelled directly as a function of these factors mentioned above or as a function of time series. In literature generally jet fuel demand forecast are conducted based on the air traffic demand forecasts and fuel intensity/efficiency improvements. Although the fuel demand for the future may depend on the fuel consumed by the aircraft engines, it is essentially related to the demand for air traffic (Cheze, Gastineu, & Chevallier, 2010).

In literature an approach called bottom up approach is used in order to be able to convert air traffic demand into fuel demand. This approach is also named as fuel intensity/efficiency approach. In that approach firstly energy efficiency or fuel intensity coefficients are obtained (expressed in mass of fuel use per air traffic) and then assumptions are made based on the historical fuel intensity trends as a percentage of annual improvement (Cheze, Gastineu, & Chevallier, 2010; Eyers, et al., 2004; IPCC, 1999; Kousoulidou & Lonza, 2016).

Currently, there is no such standard efficiency metric has been developed, thus different studies are using different metrics for the expression of efficiency. In one report published by Bethan Owen from the Manchester Metropolitan University, it is stated that there are several expressions exist in literature to express fuel efficiency. For example, to indicate efficiency in terms of the mass of fuel consumed per passenger either the metrics Available Seat Kilometers (ASK[3]) also named as Seat Kilometers Offered (SKO) or Revenue Passenger Kilometers (RPK) can be utilized. On the other hand, it is indicated that the terms mass of fuel used per Available Ton Kilometers (ATK[4]) or Revenue Tons Kilometers (RTK) are also widely used in the aviation sector (Owen, 2008).

In 2008 Macintosh and Wallace (2008), published a paper projecting the emissions of international aviation to 2025 and analyzed the effects of emission intensity improvements on emissions and with the formula below;

$$EI_N \text{ (ton } CO_2\text{/ton-km)} = E_N \text{ (ton } CO_2\text{)} / RTK_N\text{(ton-km)} \qquad (6)$$

where they defined the emission intensity (EI_N) as tons of CO_2 emissions in year N (E_N) per projected RTK in year N (RTK_N). According to the paper, the authors found that the global international emissions will increase from 416 Mt to between 876 and 1013 Mt so that fuel intensity of current aircrafts are not sufficient to overcome the growth of the emissions of the sector worldwide (Macintosh & Wallace, 2008).

Another study conducted by Cheze et. all (2010) used fuel efficiency methodology which is driven by the GDP growth and air traffic growth and estimated global jet fuel

[3] ASK = measure of passenger carrying capacity equal to the number of seats available multiplied by the number of miles or kilometers flown.

[4] ATK = measure of an airline's total capacity (both passenger and cargo) equal to the total load carried by the number of miles or kilometers flown.

demand increase between 1.4% and 2.5% annually until 2025 under couple of scenarios (Cheze, Gastineu, & Chevallier, 2010).

On the other hand, a group of researches worked on the scenario analysis of the CO_2 emissions of the China's civil aviation through 2030. In their study, as a first step they forecasted the air transport demand based on the air traffic growth predictions of the industry reports and then they assessed the impact of the key factors on the growth of the emissions which are air traffic demand, use of low carbon fuel instead of conventional jet fuel and fuel intensity improvements based on the aircraft technology improvement. They found out that growing air traffic demand is the most influential factor of the emission growth (Zhou, Wang, Yu, Chen, & Zhu, 2016). Also the study showed that fuel efficiency and replacement of fuel is unlikely to stabilize the CO_2 emissions so that they recommended additional policy framework for the control of the emissions such as carbon tax, market based scheme for the offsetting of the emissions and further study for the improvement of the fuel efficiency (Zhou, Wang, Yu, Chen, & Zhu, 2016).

Lastly, Turkey's jet fuel and bio-based jet fuel demand till 2023 is modelled and forecasted by Melikoğlu (2016). This is the only study estimating the aviation jet fuel demand for Turkey in literature. In his study, Melikoğlu developed semi-empirical models to find out the Turkey's jet fuel demand forecast with respect to Vision 2023 energy targets. The author used linear, quadratic and exponential semi-empirical models in his study and checked the accuracy of models. According to statistical results all three models are fitted well to time-line series where linear and quadratic model results are overlapped. In conclusion, the paper estimated jet fuel demand of Turkey would be between 4.230 and 7.880 billion liters in 2023 (Melikoğlu, 2016). By taking the fuel specific density as 0.8 kg/L, the jet fuel demand findings of paper for 2023 is between 3.4 Mton and 6.3 Mton of fuel in terms of mass. In addition to jet-fuel demand of Turkey, with several assumptions, the study estimated the potential bio-based jet fuel demand of Turkey between 2020 and 2023. The results showed that Turkey would need 0.154 to 0.307 billion liters of bio-based fuel until 2023 (Melikoğlu, 2016).

Likewise the studies in literature, in this thesis after air passenger traffic forecast analysis, fuel intensity approach is used for the prediction of future fuel demand of Turkey through 2030. The methodology used for fuel demand forecast is briefly explained in Chapter 4 of this thesis.

3.3. Closing Remarks

In this chapter previous studies involving air passenger traffic forecast, fuel demand forecast and CO_2 emission forecast are reviewed and summarized. There are many air passenger traffic and fuel demand forecast studies available all around the world. Yet, all studies includes different methodologies inside. For example, some forecast studies are conducted for whole world and others for a specific region or specific country. It is understood that, availability and reliability of data are among the major factors that affecting the methodology selected.

It is identified that, in most of the air traffic forecasting studies and reports of organizations regression analysis method, including variables that have causal relationship with historical data, is utilized to estimate the future values of the air traffic. So, in order to determine variables that might effect on the air passenger traffic growth more studies investigated. The studies demonstrated that econometric, demographic and social variables like GDP, total expenditures, population, inflationary rate, number of air trips per capita are widely used in literature. Combination of these variables are tested in the model to be developed for Turkey.

For the fuel demand forecasting, literature review showed that the essential methodology called fuel intensity/efficiency approach is used to convert air traffic estimates into fuel demand. In this methodology, historical energy efficiency or fuel intensity coefficients (expressed in mass of fuel use per air traffic) are calculated and by making assumptions based on historical trends as a percentage of annual improvement, air traffic estimates are converted into jet fuel demand estimations.

CHAPTER 4

METHODOLOGY AND DATA SOURCES

4.1. Methodology of the Study

In this chapter methodology used for the forecasting of CO_2 emissions originating from international aviation activities of Turkey through 2030 are explained. The overview of the methodology used in this thesis is visualized in Figure 4.1.

As can be seen from Figure 4.1, outputs of the study can be listed as;

- air passenger traffic demand forecast,
- fuel demand calculation and
- CO_2 calculations.

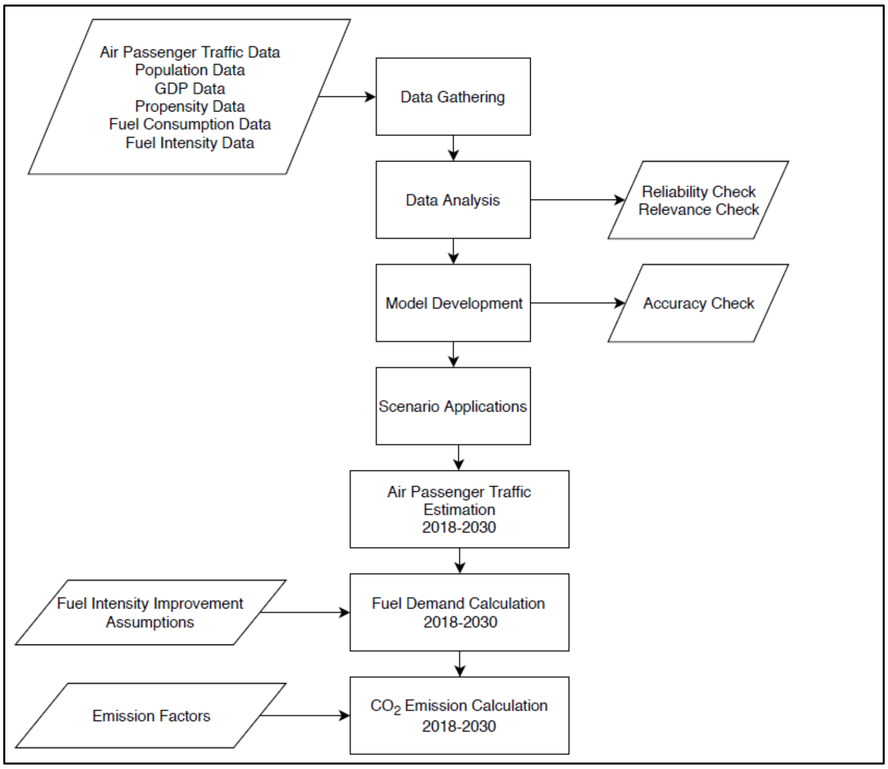

Figure 4.1 Methodology of the study

4.2. Model Development and Scenario Application

In order to develop a regression model capable of estimating the air passenger traffic, firstly international passenger air traffic data in terms of RPK between 2005 and 2017 are gathered from the Annual Reports of the Council of ICAO (ICAO, 2017).

After collecting the RPK data, several factors affecting the air passenger traffic are identified. The key influential factors are categorized in 3 different groups which are economic, demographic and social factors. It is decided to include one variable from each category in the regression model to be established. Different variables from each category are listed and several combination of variables are tested during the development stage of the model. Data to be included into the model is analyzed. However, some of the variables did not well fit into the model and some of them gave results contrary to their real effects. After various attempts by considering the statistical consistency and accuracy of the model, it is decided to include real GDP which is inflation adjusted value (sometimes named as constant dollar GDP), population, and propensity to air travel (number of air trips per capita) as independent variables into the regression model and model is run. The developed model gave results that are compatible with the effects of variables on the air traffic. Also R square value of the model is close to one and Mean Absolute Percentage Error (MAPE) value of the model was below 10%.

After obtaining the most representative model, three scenarios are applied to the model. Thus, air passenger traffic is forecasted under three different scenarios representing low, medium and high growth rates of each variable between 2018 and 2030.

After completing air passenger forecasts, jet fuel demand is calculated. Since, jet fuel demand cannot be modelled directly, as mentioned in Chapter 3.2 the essential fuel intensity approach is used in order to convert air traffic data into fuel demand. To do this, equation (7) below is used:

$$FD_Y = RPK_Y * FI_Y \quad (7)$$

where

FD_Y : fuel demand in year Y (ton/year),

RPK_Y : forecasted air passenger traffic in year Y(million passenger-kilometers) and

FI_Y : Fuel intensity of year Y (tons of fuel per million RPK).

Y= year

Based on historical data and reports of industry and international organizations three different fuel intensity improvement scenarios are set and corresponding fuel demand are estimated. Figure 4.2 visualizes the scenario setting and applications steps. Moreover, the figure summarizes process for obtaining nine different fuel demand and CO_2 emission which are outputs of the scenarios.

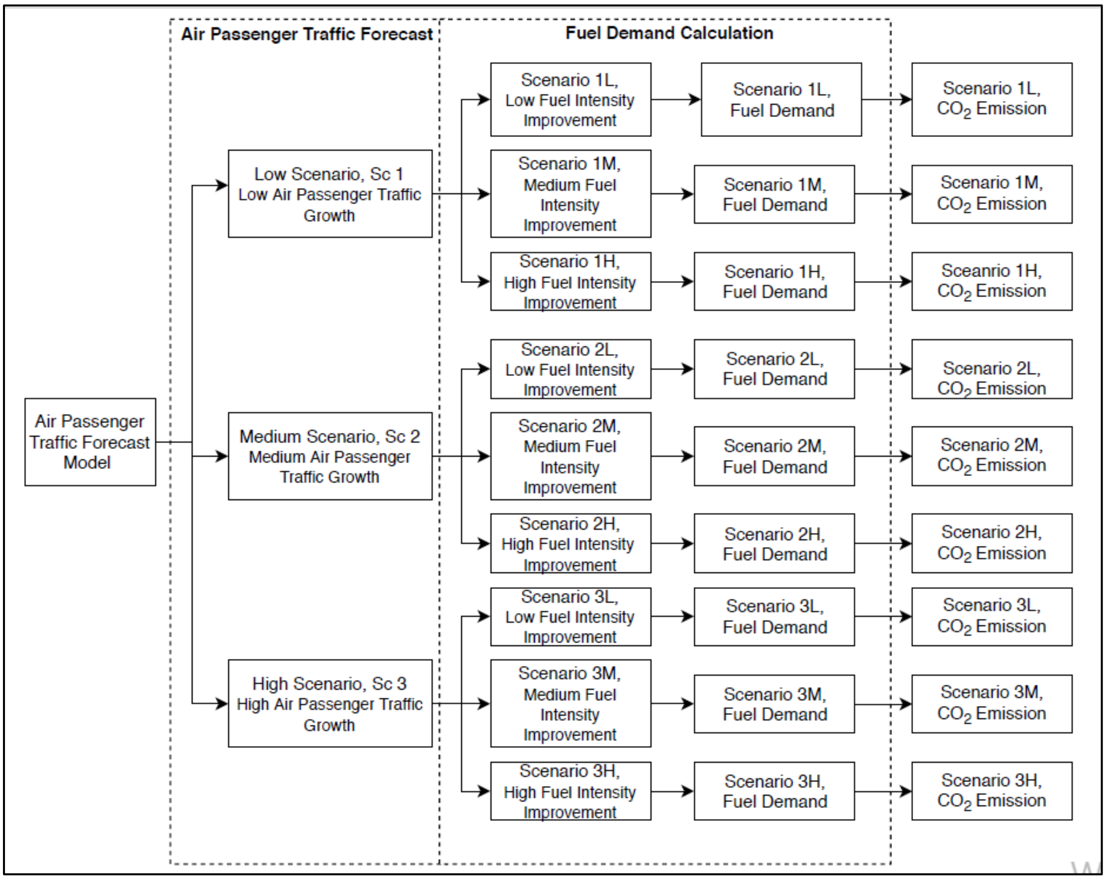

Figure 4.2 Overview of scenario setting and output of the scenarios

4.3. CO_2 Emission Calculation Method

After obtaining fuel demand data for nine different scenarios, Tier 1 method of the IPCC is used to estimate future CO_2 emissions since only fuel data is available.

4.4. Data Sources

In this chapter data required for model development and emissions calculation that are gathered from different resources are presented.

4.4.1. Air Passenger Traffic Data

In this chapter air passenger traffic data representing the growth of aviation sector in Turkey are demonstrated. As mentioned in Chapter 1.1 to present air passenger growth RPK term is used which is the measure of the volume of passengers in aviation industry equal to one revenue passenger transported one kilometer (passenger-km).
Data is obtained from the Annual Reports of the ICAO Council which is published every year on ICAO web-site (ICAO, 2001). Since base year chosen as 2005, in Table 4.1 passenger air traffic developments on international services for years 2005-2017 are provided for Turkey.

Table 4.1 International RPK data for Turkey (ICAO, 2001)

Years	International Revenue Passenger Kilometer (million passenger-km)
2005	23,082
2006	24,895
2007	32,230
2008	46,643
2009	51,357
2010	61,931
2011	77,495
2012	91,520
2013	111,450
2014	127,805

Years	International Revenue Passenger Kilometer (million passenger-km)
2015	142,315
2016	145,435
2017	160,918

4.4.2. Economic, Demographic and Social Indicator Data

In order to forecast air passenger traffic, a regression model is developed in this thesis. The regression model employed economic, demographic and social variables affecting the growth of the air passenger traffic.

As an economic indicator real GDP which is inflation adjusted value (sometimes named as constant dollar GDP) is utilized. GDP with constant 2010 USD data is obtained from World Bank open database and presented below (World Bank, 2019).

Table 4.2 Real GDP (constant 2010 USD) data of Turkey (World Bank, 2019)

Years	GDP (constant 2010 USD) (billions)
2005	658
2006	705
2007	740
2008	747
2009	712
2010	772
2011	858
2012	899
2013	975
2014	1,025
2015	1,088
2016	1,123
2017	1,206

As demographic variable population of Turkey is included into regression analysis. The population data is obtained from World Bank open database and presented in Table 4.3 (World Bank, 2019).

Table 4.3 Population data of Turkey (World Bank, 2019)

Years	Population (millions)
2005	67.90
2006	68.76
2007	69.60
2008	70.44
2009	71.34
2010	72.33
2011	73.41
2012	74.57
2013	75.79
2014	77.03
2015	78.27
2016	79.51
2017	80.75

As for the social indicator the term propensity to air travel (number of air trips per capita) is selected. The term indicates air travel behavior of residents in Turkey. In order to determine propensity, firstly air transport-registered carrier departures data of Turkey is obtained from World Bank open database where registered carrier departure data is defined as domestic takeoffs and takeoffs abroad of air carriers registered within the country. World Bank published this data based on ICAO Civil Aviation Statistics of the World and ICAO staff estimates (World Bank, 2019). Secondly, in order to convert this data into propensity, registered carrier departure data is divided to population data provided in Table 4.3. As a result, propensity data of Turkey is obtained and provided below.

Table 4.4 Propensity data of Turkey (World Bank, 2019; TURKSTAT, 2019)

Years	Propensity (registered air carrier departures per capita)
2005	0.0021
2006	0.0026
2007	0.0028
2008	0.0031

Years	Propensity (registered air carrier departures per capita)
2009	0.0038
2010	0.0051
2011	0.0057
2012	0.0064
2013	0.0075
2014	0.0082
2015	0.0090
2016	0.0094
2017	0.0092

4.4.3. Fuel Consumption Data

In this chapter jet-fuel consumption data utilized for the calculation of the historical and current CO_2 emissions are presented. Data is obtained from DGCA of Turkey with permission which is a public entity with private budget established under the auspices of the Ministry of Transport and Infrastructure. The permission document is provided in the Appendix A.

DGCA of Turkey provided, without specifying the names of the operators, annual total jet-fuel consumption data for the Turkish registered airline operators conducting international flights of the aviation sector. On Table 4.5 jet-fuel consumption data are shown for the 2005-2017 time period in metric tons for international flights.

Table 4.5 Jet-fuel consumption data for international flights between 2000 and 2017 (SHGM, 2019)

Years	International Jet-Fuel Consumption (tons)
2005	703,750
2006	836,798
2007	928,091
2008	994,277
2009	1,264,879
2010	1,936,212
2011	2,722,153
2012	3,025,424

Years	International Jet-Fuel Consumption (tons)
2013	3,645,677
2014	4,052,756
2015	4,832,765
2016	4,819,823
2017	5,165,275

4.4.4. Fuel Specific Emission Factors

In this chapter emission factors for the different type of fuels used in the aviation sector are provided. For the determination of the fuel specific emission factors information on the carbon content and net calorific value of the fuels must be known. In addition to carbon content and net calorific value, oxidation factor is needed. In the IPCC Guidelines which are published in 1996 there was a list of default for oxidation factors values which were determined from the carbon content of the ash that remains. However, in the latest guidelines published by IPCC oxidation factor is accepted as 1 in order to eliminate calculation step for the oxidation (German Environment Agency, 2016). For this reason, within that thesis oxidation factor of all aviation fuels are assumed as 1.

The table below summarizes the default net calorific values, CO_2 Emission Factors, oxidation factor and mass basis CO_2 Emission Factors for different type of fuels being used in the aviation sector based on the 2006 IPCC Guidelines (IPCC, 2006).

Table 4.6 Fuel specific values (IPCC, 2006)

Fuel Type	Net Calorific Value (GJ/ton)	CO_2 Emission Factors (kg CO_2 /GJ)	Oxidation Factor	Mass Basis CO_2 Emission Factors (ton CO_2/ton)
Aviation gasoline	44.3	70	1.0	3.101
Jet gasoline	44.3	70	1.0	3.101
Jet kerosene	44.1	71.5	1.0	3.153
Other kerosene	43.8	71.9	1.0	3.149

In the context of this thesis, for the calculation of emissions only the emission conversion factor of jet kerosene which is equal to 3.153 ton of CO_2/ ton of fuel consumed is used since all the airlines registered to Turkey are using this type of fuel in their flights.

4.4.5. Fuel Intensity Data

In this Chapter historical fuel intensity data calculated are presented. The fuel intensity data is calculated by dividing the international fuel consumption data provided in Table 4.5 into international RPK data provided in Table 4.1.

Table 4.7 Historical Fuel Intensity Data

Year	Fuel Consumption (tons)	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)
2005	703,750	23,082	30.49
2006	836,798	24,895	33.61
2007	928,091	32,230	28.80
2008	994,277	46,643	21.32
2009	1,264,879	51,357	24.63
2010	1,936,212	61,931	31.26
2011	2,722,153	77,495	35.13
2012	3,025,424	91,520	33.06
2013	3,645,677	111,450	32.71
2014	4,052,756	127,805	31.71
2015	4,832,765	142,315	33.96
2016	4,819,823	145,435	33.14
2017	5,165,275	160,918	32.10

4.5. Future Estimates of the Parameters under Different Scenarios

As briefly explained in Chapter 3, to forecast air passenger traffic, multiple regression analysis is conducted with the use of computer-based model. Inflation adjusted GDP, population and propensity are used as independent variables.

While conducting air passenger forecast three different scenarios are defined which are Low Scenario, Medium Scenario, and High Scenario. The medium scenario represents the business as usual growth trend and includes medium growth rate assumptions along the forecast time horizon. Whereas low growth rate assumptions made under low scenario and higher growth rate assumptions in high scenario. Under each scenario defined, different possible values of the variables are predicted for Turkey through 2030.

For population, projection data produced and published by Turkish Statistical Institute is used. Like in our thesis, the document called TURKSTAT Population Projections 2018-2080 includes medium , low and high scenarios. So, without making different assumptions, the projected population between 2017 and 2030 is directly used in this thesis (TURKSTAT, 2019). Figure 4.3 shows the growth pattern of population under different scenarios.

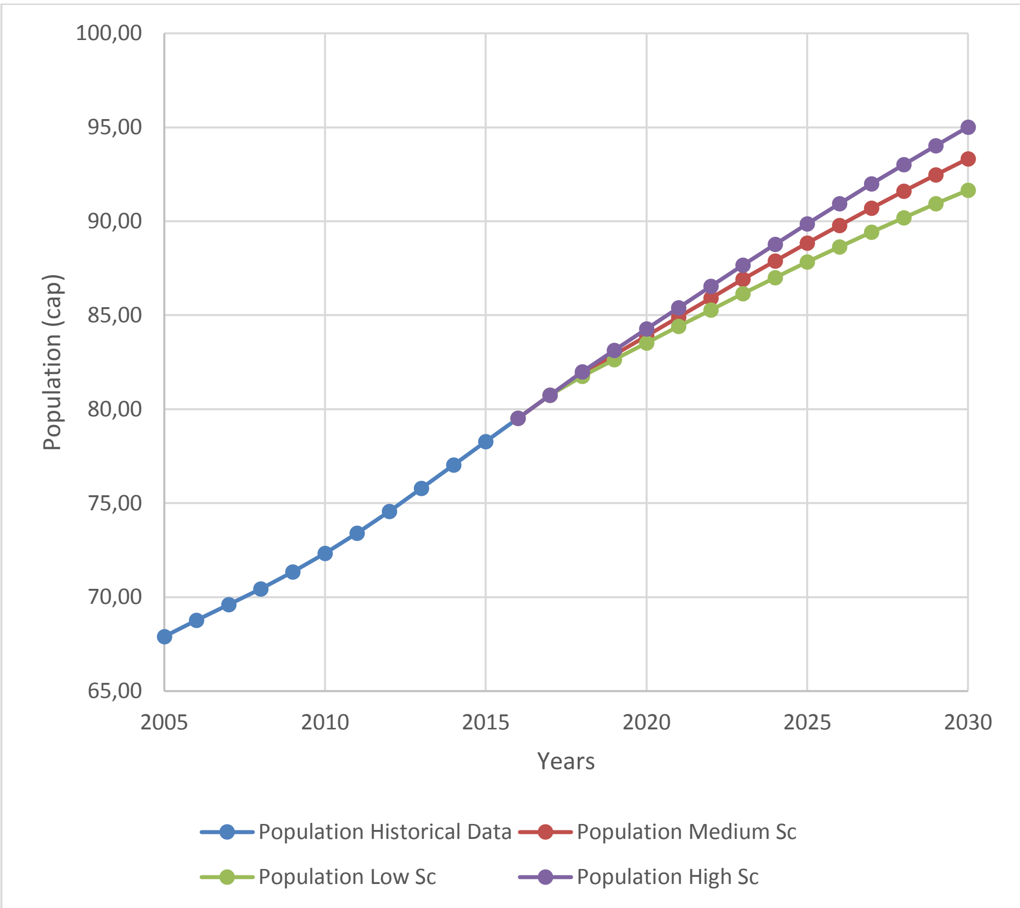

Figure 4.3 Population growth under different scenarios (TURKSTAT, 2019)

Due to the unstable economy in the country, for real GDP projection assumptions of Turkey between 2017 and 2030 several resources are utilized. The latest GDP data provided in this thesis was for 2017, so for 2018 the real growth rates published by International Monetary Fund (IMF) are utilized. According to the World Economic Outlook report published by IMF in 2019 April, in year 2018 Turkey's real GDP increased 2.6 percent with respect to 2017 and in 2019 it is expected to decrease 2.5 percent with respect to 2018 (IMF, 2019). So, the real growth value and the estimation are directly used in the model for 2017-2019 interval.

On the other hand, for 2019-2030 period; medium and long-term forecasts conducted by IMF, Organization for Economic Co-operation and Development (OECD) and PricewaterhouseCoopers (PwC) which is a worldwide recognized consultancy company providing services to the business world in the field of auditing, consultancy and tax services are used. Table 4.8 summarizes the different predictions of different organizations for Turkey and world (IMF, 2019; OECD, 2019; PWC, 2017).

Table 4.8 Predictions of annual growth rates of GDP (IMF, 2019; OECD, 2019; PWC, 2017)

Predictor	Forecast Period	World GDP (%)	Turkey GDP (%)
IMF	2018-2024	3.3	3.1
PwC	2016-2050	2.6	3.5
OECD	2016-2030	3.1	5.0

By taking the highest and lowest GDP growth predictions of the sources into consideration, annual 4% GDP growth is assumed for medium scenario, annual 3.1% GDP growth is assumed for low scenario and annual 5% GDP growth is assumed for high scenario through 2030 under this thesis. Table 4.9 summarizes the assumptions made for the compound annual growth rate of the real GDP and Figure 4.4 visualizes the growth pattern of real GDP through 2030 under different scenarios.

Table 4.9 Compound annual growth rate assumptions for GDP

Real GDP	Forecast Period	Compound Annual Growth Rate Assumption
Low Scenario	2019-2030	3.1%
Medium scenario	2019-2030	4.0%
High Scenario	2019-2030	5.0%

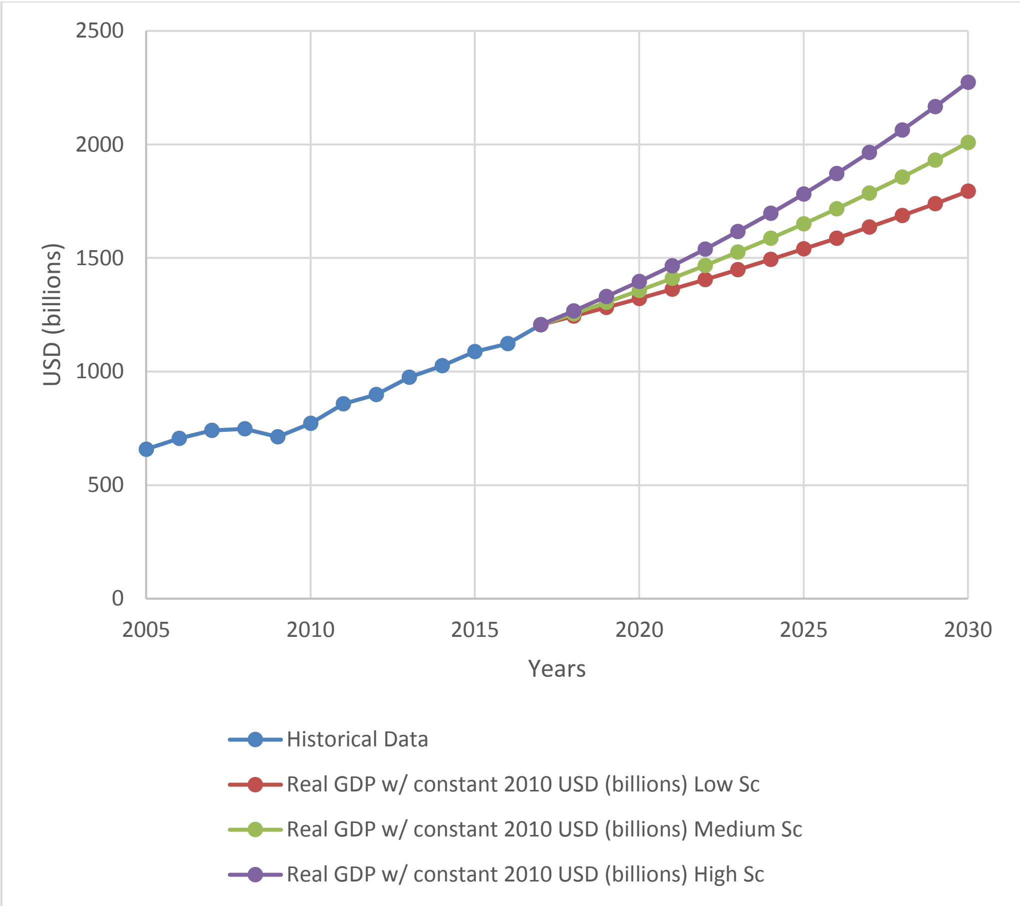

Figure 4.4 Real GDP growth under different scenarios

The last variable used in the regression analysis is propensity which is the number of air trips per capita. While making assumptions on this variable, firstly increase in the number of registered air carrier departures is forecasted based on historical data available. According to the historical data between 2005 and 2017 average compound annual growth rate of the registered air departures is calculated as 15%. On the other hand, in the last five years the compound annual growth rate is calculated as 9%. This is because the aviation sector in Turkey showed a rapid increase after the implementation liberalization policies so that after 2003 sharp increment observed in the number of departures. The data shows that still today the number of departures is increasing but not growing aggressively as it was in past. In 2016, due to the Turkey's downing of a Russian jet the bilateral relations came to a halt and this situation affected the aviation sector deeply. Even in 2016, registered air carrier departures of Turkey increased but the lowest annual growth rate is observed with 5% increase.

By taking these circumstances into account, for the registered air carrier departures, annual 7% growth is assumed for medium scenario, annual 5% growth is assumed for low scenario and annual 9% growth is assumed for high scenario through 2030 under this thesis. After obtaining number of departures, the data is divided into the population predictions under each scenario correspondingly. So that propensity values for 2017-2030 period is predicted. Figure 4.5 shows the propensity growth under different scenarios.

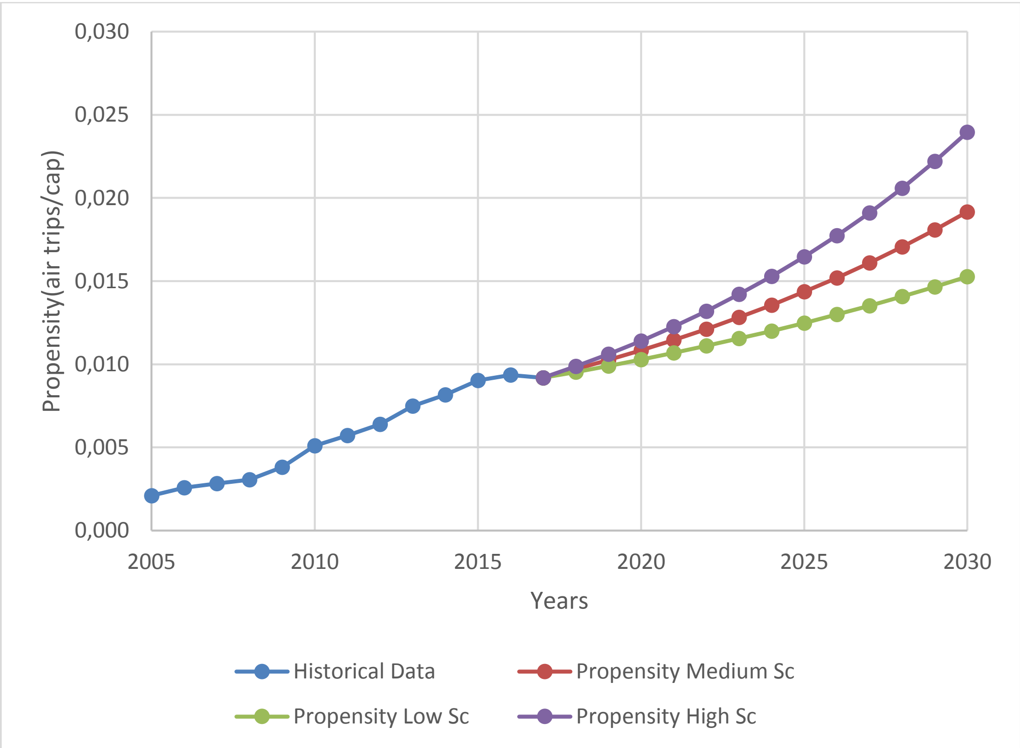

Figure 4.5 Propensity growth under different scenarios

The summary of the forecast scenarios of the air passenger traffic by combining scenarios for different variables is given in the Table 4.10.

Table 4.10 Summary of the scenarios for air passenger traffic demand forecast

Scenario	Combination of Scenarios for Variables	Air Passenger Traffic Forecast Scenario Indicator
Low Scenario	Real GDP, Low Sc Population, Low Sc Propensity, Low Sc	Sc 1
Medium Scenario	Real GDP, Medium Sc Population, Medium Sc Propensity, Medium Sc	Sc 2
High Scenario	Real GDP, High Sc Population, High Sc Propensity, High Sc	Sc 3

4.6. Fuel Efficiency Estimates under Different Scenarios

As indicated in Chapter 3, fuel demand is not directly modelled as a function of time. In order to convert the air passenger traffic data into fuel demand, emission intensity or energy efficiency methods are utilized in literature. These methods are essential because jet fuel demand rely on the both air traffic demand and energy efficiency (i.e. fuel efficiency). Energy efficiency also depends on several variables like air traffic management, operational improvements and aircraft technology.

To reflect fuel efficiency improvement in this study, fuel intensity approach is used and three different fuel intensity improvement scenarios are defined. While making assumptions on the fuel intensity improvement data,

- a study indicating energy gains for 1983-2006 is between 1.5% and 2.2% per year (Lee, Lukachko, & Waitz, 2004),
- ICAO’s aspirational goal which is improving 2% annual fuel efficiency and
- Turkey’s performance for 2005-2017 period which was 1% are taken into account.

The study conducted by Lee and others (2004) affirms that the fuel efficiency is dependent on the aircraft engines. The biggest improvement observed after the development of turbojet and turbofan engines. However there is a discontinuation in the aircrafts' energy efficiency improvement. Consequently the study, reveals that energy efficiency of aircrafts improved between 1.5% and 2.2% between years 1983 and 2006 (Lee, Lukachko, & Waitz, 2004).

By taking all these into account, annual 1% fuel improvement is assumed as the low scenario, whereas annual 1.5% is considered as medium scenario and 2.5% annual fuel intensity improvement is accepted as high scenario. Table 4.11 summarizes the fuel demand forecast scenarios.

Table 4.11 Fuel intensity improvement scenarios for fuel demand forecast

Scenario	Fuel Demand Forecast Scenario Indicator	Forecast Period	Annual Fuel Intensity Improvement
Low Scenario	Sc L	2017-2030	1.0%
Medium scenario	Sc M	2017-2030	1.5%
High Scenario	Sc H	2017-2030	2.5%

4.6.1. Fuel Intensity Estimates for Scenario L

In this Chapter, based on fuel efficiency estimates made in Chapter 4.6, corresponding fuel intensity values estimated for future is presented. While calculating future fuel intensity values, the fuel intensity data calculated for year 2017 provided in Table 4.7 is utilized as the starting point for the estimations. Under Sc L, each year fuel intensity value is improved 1% compared to previous year. Table 4.12 presents the future fuel intensity values as tons of fuel consumed per million RPK performed. Fuel intensity improvement means, increase in the fuel efficiency so that decrease in the fuel intensity value.

Table 4.12 Fuel intensity data for future under Sc L

Years	Annual Fuel Intensity Improvement	Fuel Intensity (tons of fuel/million RPK)
2017	-	**32.10**
2018	1%	31.78
2019	1%	31.46
2020	1%	31.15
2021	1%	30.83
2022	1%	30.53
2023	1%	30.22
2024	1%	29.92
2025	1%	29.62
2026	1%	29.32
2027	1%	29.03
2028	1%	28.74
2029	1%	28.45
2030	1%	28.17

4.6.2. Fuel Intensity Estimates for Scenario M

In this Chapter, based on fuel efficiency estimates made in Chapter 4.6, corresponding fuel intensity values estimated for future is presented. While calculating future fuel intensity values, the fuel intensity data calculated for year 2017 provided in Table 4.7 is utilized as the starting point for the estimations. Under Sc M, each year fuel intensity value is improved 1.5% compared to previous year. Table 4.13 presents the future fuel intensity values as tons of fuel consumed per million RPK performed.

Table 4.13 Fuel intensity data for future under Sc M

Years	Annual Fuel Intensity Improvement	Fuel Intensity (tons of fuel/million RPK)
2017	**-**	**32.10**
2018	1.5%	31.62
2019	1.5%	31.14
2020	1.5%	30.68
2021	1.5%	30.22
2022	1.5%	29.76
2023	1.5%	29.32

Years	Annual Fuel Intensity Improvement	Fuel Intensity (tons of fuel/million RPK)
2024	1.5%	28.88
2025	1.5%	28.44
2026	1.5%	28.02
2027	1.5%	27.60
2028	1.5%	27.18
2029	1.5%	26.77
2030	1.5%	26.37

4.6.3. Fuel Intensity Estimates for Scenario H

In this Chapter, based on fuel efficiency estimates defined in Chapter 4.6, corresponding fuel intensity values estimated for future is presented. While calculating future fuel intensity values, the data calculated for year 2017 provided in Table 4.7 is utilized as the starting point for the estimations. Under Sc H, each year fuel intensity value is improved 2.5% compared to previous year. Table 4.14 presents the future fuel intensity values as tons of fuel consumed per million RPK performed.

Table 4.14 Fuel intensity data for future under Sc H

Years	Annual Fuel Intensity Improvement	Fuel Intensity (tons of fuel/million RPK)
2017	**-**	**32.10**
2018	2.5%	31.30
2019	2.5%	30.51
2020	2.5%	29.75
2021	2.5%	29.01
2022	2.5%	28.28
2023	2.5%	27.58
2024	2.5%	26.89
2025	2.5%	26.21
2026	2.5%	25.56
2027	2.5%	24.92
2028	2.5%	24.30
2029	2.5%	23.69
2030	2.5%	23.10

To visualize the difference in fuel intensity values under different scenarios, Figure 4.6 shows the fuel intensity values for different fuel efficiency improvement assumptions between 2017 and 2030. The figure represents decrease pattern in the fuel intensity values with respect to time, which means less fuel is going to be used to carry more air passenger traffic in other words more fuel efficient flights could occur in near future.

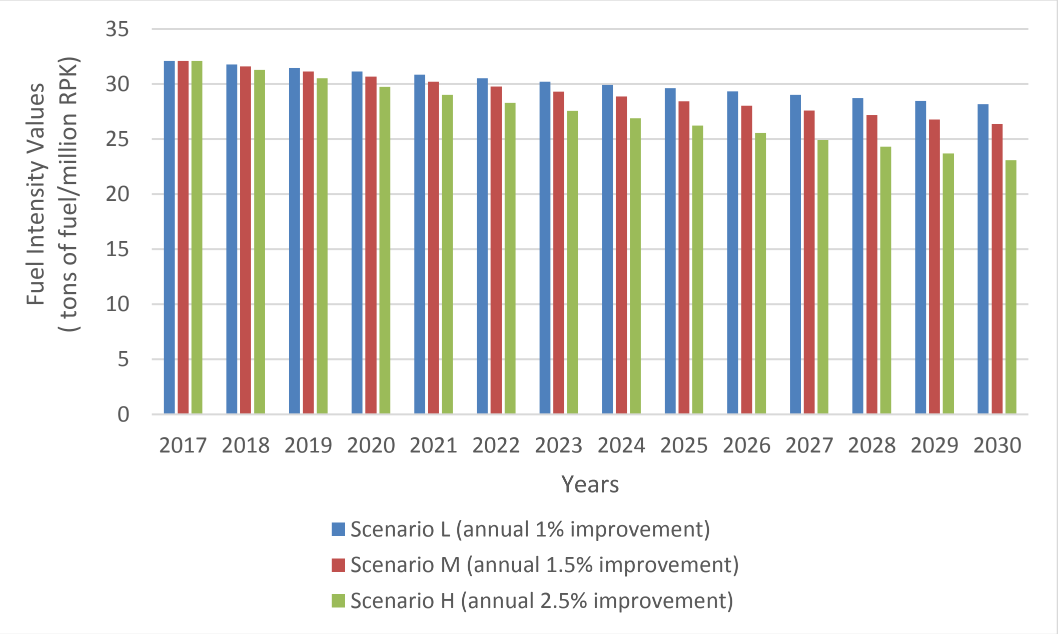

Figure 4.6 Fuel intensity values under different scenarios

4.7. Closing Remarks

In this chapter methodology used within this thesis is explained briefly. Steps followed during the model developing and scenario setting are explained in details. Moreover, data gathered for the forecast study and data used for the calculations of fuel demand and CO_2 emission are presented separately.

CHAPTER 5

RESULTS

5.1. Demand Model

As explained in Chapter 3, a regression based model is developed and run based on three scenarios to estimate air passenger traffic. With the use of air passenger traffic and indicator data presented in Chapter 4, regression model is established first and then the coefficients of the model, correlation between the variables are found. According to regression analysis model takes the form;

$$Y_y = a + b\,X_{1,\,y} + c\,X_{2,\,y} + d\,X_{3,\,y} \qquad (8)$$

where;

Y = air passenger traffic in terms of million RPK in year y

a = intercept,

b, c, d = coefficients

X_1 = Real GDP with constant 2010 USD in terms of billions in year y

X_2 = Population in terms of million capita in year y

X_3 = Propensity in terms of air trips per 100capita in year y

y= year

The correlation matrix of the independent variables is shown in Table 5.1. According to the results the variables used in this model are interrelated. For example, Real GDP has the correlation coefficient 0.971 with propensity and 0.985 with the population. Despite having relatively high correlation coefficients, this situation does not refer a sharp relation of causality. On the contrary, they can develop differently at specific time intervals without cause-effect interaction.

Table 5.1 Correlation matrix of independent variables

	RPK	Real GDP	Population	Propensity
RPK	1.000	0.988	0.996	0.990
Real GDP	0.988	1.000	0.985	0.971
Population	0.996	0.985	1.000	0.988
Propensity	0.990	0.971	0.988	1.000

Table 5.2 below is showing the coefficients, Standard Error, T Value and P Value representing the standard error of the linear regression model.

Table 5.2 Coefficients of the regression model

Variables	Coefficient	Std Error	T-Stat	P-Value
Constant	-378,588.4	14,8919.3	-2.542	3.16%
Real GDP (billions)	69.1	37.4	1.846	9.80%
Population (millions)	4,999.9	2,491.3	2.007	7.57%
Propensity (air trips/100 cap)	56,775.9	27,336.9	2.077	6.76%

Table 5.3 below shows the R square, adjusted R square, Root Mean Standard Error (RMSE), and Mean Absolute Percentage Error (MAPE) values of the linear regression model for 13 observations between 2005 and 2017. The R square is found as 0.995 and adjusted R square is 0.993 which are quite good. On the other hand, RMSE metric which compares the forecasted data with the predicted data and generally used in climatology, forecasting and regression analysis to assess the results and MAPE measures the size of errors in terms of percentages are also shown (Barnston, 1992). Lastly, the average of percentage of residuals in our model is calculated as 0.08%.

Table 5.3 Summary of the fit

R square	0.995
R square Adjusted	0.993
Observations	13
RMSE	3314.7
MAPE	6.29%

Based on the model established, Table 5.4 shows the upper and lower predictions of the model and corresponding errors. Also Figure 5.1 shows how well the model fits with the actual data.

Table 5.4 Model predictions and errors

Years	Actual RPK (millions)	Predicted RPK (millions)	Lower Prediction (millions)	Upper Prediction (millions)	Error (± millions)
2005	23,082	18,288	28,562	8,013	10,274
2006	24,895	28,673	38,971	18,375	10,298
2007	32,230	36,427	46,638	26,216	10,211
2008	46,643	42,814	52,887	32,740	10,073
2009	51,357	48,870	60,314	37,426	11,444
2010	61,931	65,346	75,714	54,977	10,368
2011	77,495	80,094	89,547	70,640	9,453
2012	91,520	92,701	102,215	83,187	9,514
2013	111,450	110,297	120,219	100,374	9,922
2014	127,805	123,925	133,801	114,050	9,876
2015	142,315	139,020	149,181	128,859	10,161
2016	145,435	149,909	159,893	139,924	9,984
2017	160,918	160,707	172,686	148,728	11,979

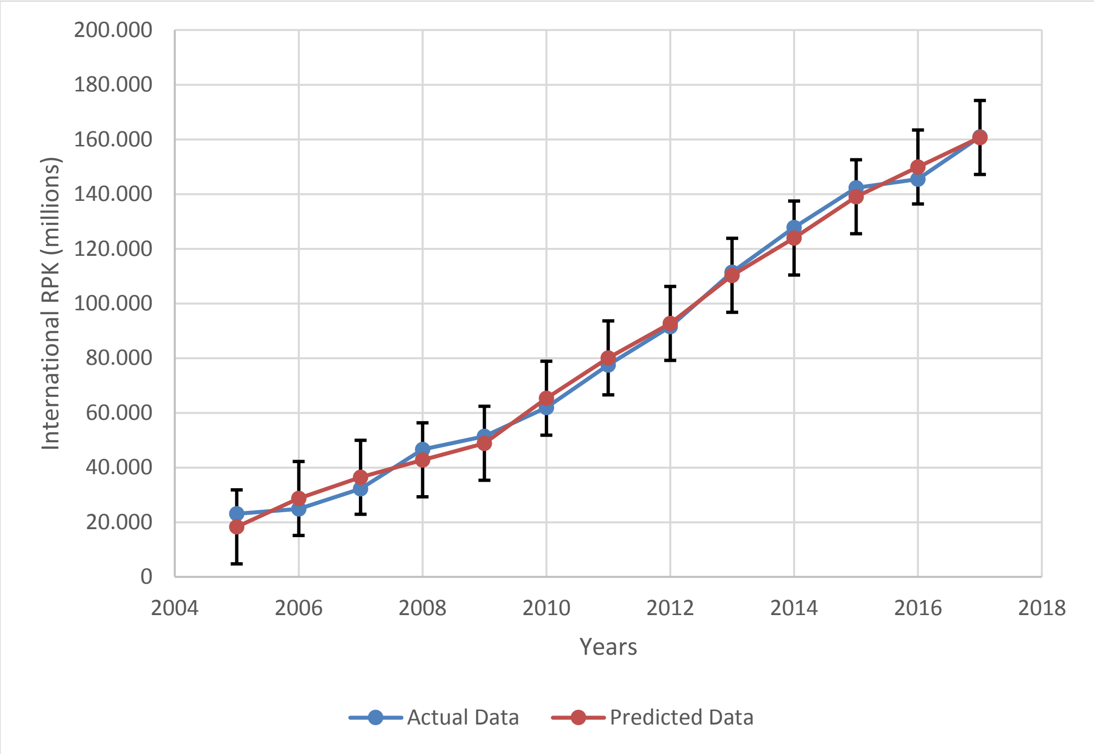

Figure 5.1 Actual vs predicted RPK

5.1.1. Sensitivity Analysis

In this chapter sensitivity analysis conducted on the key variables that are included into the air passenger traffic model which are real GDP, population, and propensity. The three variables have different impacts on the air passenger traffic demand. With the use of *Microsoft Excel* elasticities of the variables are found and summarized in Table 5.5.

Table 5.5 Elasticity values of the model variables

Variable	Elasticity
Real GDP	0.73
Population	4.37
Propensity	0.38

According to the results it is found that population has the strongest impact on the air passenger traffic model while GDP and propensity have weaker effects. The results show that 1% change of population changes the RPK value 4.37% whereas GDP and propensity changes 0.73% and 0.38% respectively. In order to visualize the impact of variables Tornado diagram of variables for 2013 data are provided in Figure 5.2. Tornado diagram provides a graphical representation of the degree to which the result is sensitive.

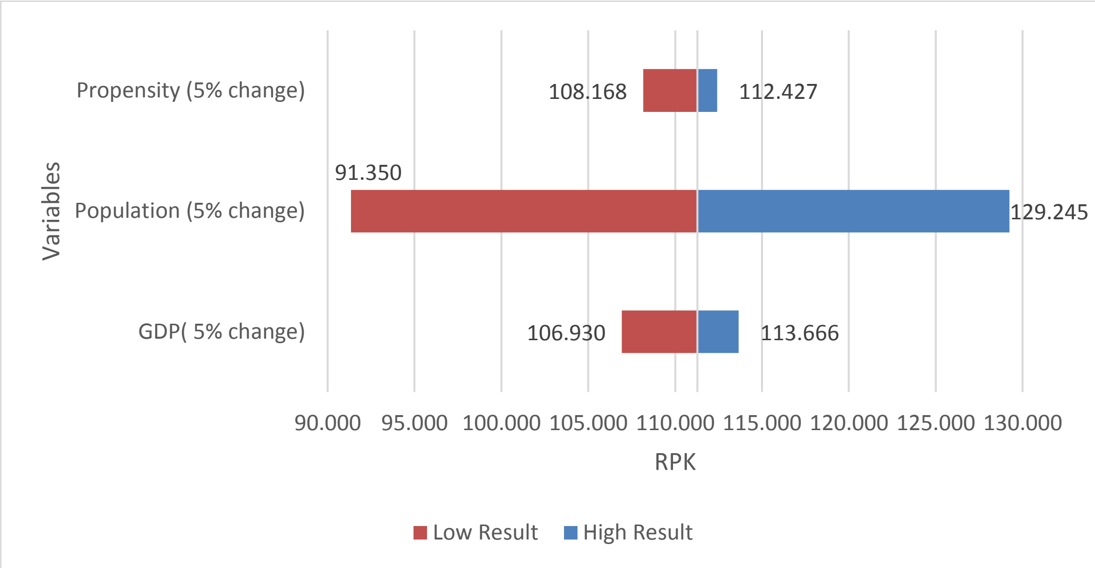

Figure 5.2 Tornado diagram of variables for 2013

5.2. Air Passenger Traffic Model Results

5.2.1. Results of Scenario 1

Low Scenario indicated as Sc 1 in this thesis, employs low growth assumptions of independent variables as summarized in Table 5.6.

Table 5.6 Scenario 1 description

Scenario	Combination of Scenarios for Variables	Air Passenger Traffic Forecast Scenario Indicator
Low Scenario	Real GDP, Low Sc Population, Low Sc Propensity, Low Sc	Sc 1

2018-2030 values for independent variables under low growth assumptions are incorporated into regression model and results for the Sc 1 are found as follows.

Table 5.7 Scenario 1 model results

Years	International RPK of Turkey (millions)	Errors (±)	Annual Change (%)
2017	**160,918**		-
2018	169,503	13,223	5.3%
2019	174,132	15,118	2.7%
2020	183,478	15,977	5.4%
2021	192,774	16,832	5.1%
2022	202,209	17,663	4.9%
2023	211,613	18,418	4.7%
2024	221,603	18,688	4.7%
2025	231,631	18,868	4.5%
2026	241,629	19,000	4.3%
2027	251,596	19,106	4.1%
2028	262,119	18,750	4.2%
2029	272,610	18,485	4.0%
2030	283,140	18,376	3.9%
Compound Annual Growth Rate (%)			4.6%

5.2.2. Results of Scenario 2

As summarized in Chapter 5.1, the medium scenario indicated as Sc 2 includes the medium growth assumptions of independent variables as summarized in Table 5.8.

Table 5.8 Scenario 2 description

Scenario	Combination of Scenarios for Variables	Air Passenger Traffic Forecast Scenario Indicator
Medium scenario	Real GDP, Medium Sc Population, Medium Sc Propensity, Medium Sc	Sc 2

After integrating the medium growth assumptions of variables for 2018-2030 period into the regression model, the results obtained for air passenger traffic for 2018-2030 are shown in Table 5.9.

Table 5.9 Scenario 2 model results

Years	International RPK of Turkey (millions)	Errors (±)	Annual Change (%)
2017	**160,918**		
2018	171,288	12,824	6.4%
2019	177,653	14,642	3.7%
2020	188,927	15,186	6.3%
2021	201,406	15,029	6.6%
2022	213,405	15,192	6.0%
2023	226,110	15,037	6.0%
2024	239,489	14,585	5.9%
2025	252,858	14,301	5.6%
2026	266,314	14,349	5.3%
2027	280,376	14,718	5.3%
2028	295,113	15,810	5.3%
2029	309,958	17,831	5.0%
2030	325,359	20,879	5.0%
Compound Annual Growth Rate (%)			5.8%

5.2.3. Results of Scenario 3

High Scenario indicated as Sc 3 in that thesis, is originating from the high growth rate assumptions of the independent variables. Table 5.10 describes the combination of assumptions made under Sc 3.

Table 5.10 Scenario 3 description

Scenario	Combination of Scenarios for Variables	Air Passenger Traffic Forecast Scenario Indicator
High Scenario	Real GDP, High Sc Population, High Sc Propensity, High Sc	Sc 3

Future values determined for independent variables under high growth rate assumptions are placed into the regression model and forecast of air passenger traffic for 2018-2030 period is found and shown in the Table 5.11.

Table 5.11 Scenario 3 model results

Years	International RPK of Turkey (millions)	Errors (±)	Annual Change (%)
2017	160,918		7.5%
2018	173,049	12,418	4.4%
2019	180,585	14,578	8.0%
2020	194,995	14,219	7.8%
2021	210,180	13,596	7.3%
2022	225,534	13,167	7.1%
2023	241,636	12,843	7.0%
2024	258,497	13,254	6.8%
2025	276,079	14,768	6.4%
2026	293,827	17,482	6.5%
2027	312,939	21,675	6.3%
2028	332,763	27,441	6.2%
2029	353,362	34,233	6.2%
2030	375,270	42,668	7.5%
Compound Annual Growth Rate (%)			6.7%

5.2.4. Summary of Air Passenger Traffic Forecast Results

Figure 5.3 visualizes the summary of the forecasted international RPK values that are listed in Table 5.7, Table 5.9 and Table 5.11. The figure also involves the growth trend of the historical data. According to historical data, after year 2005 continuous growth trend is observed in the international air passenger traffic until year 2016.

In 2016, due to downing of the Russian warplane, Turkish-Russian relations was negatively affected and this situation was reflected in aviation sector. In 2016, Russia banned charter flights between Russia and Turkey as a result of this decision certain amount of decrease occurred in the air passenger traffic data of Turkey. However, following the normalization of relations with Russia, the growth trend continued. And the assumptions made in the context of this thesis also consider that the growth trend will continue through 2030.

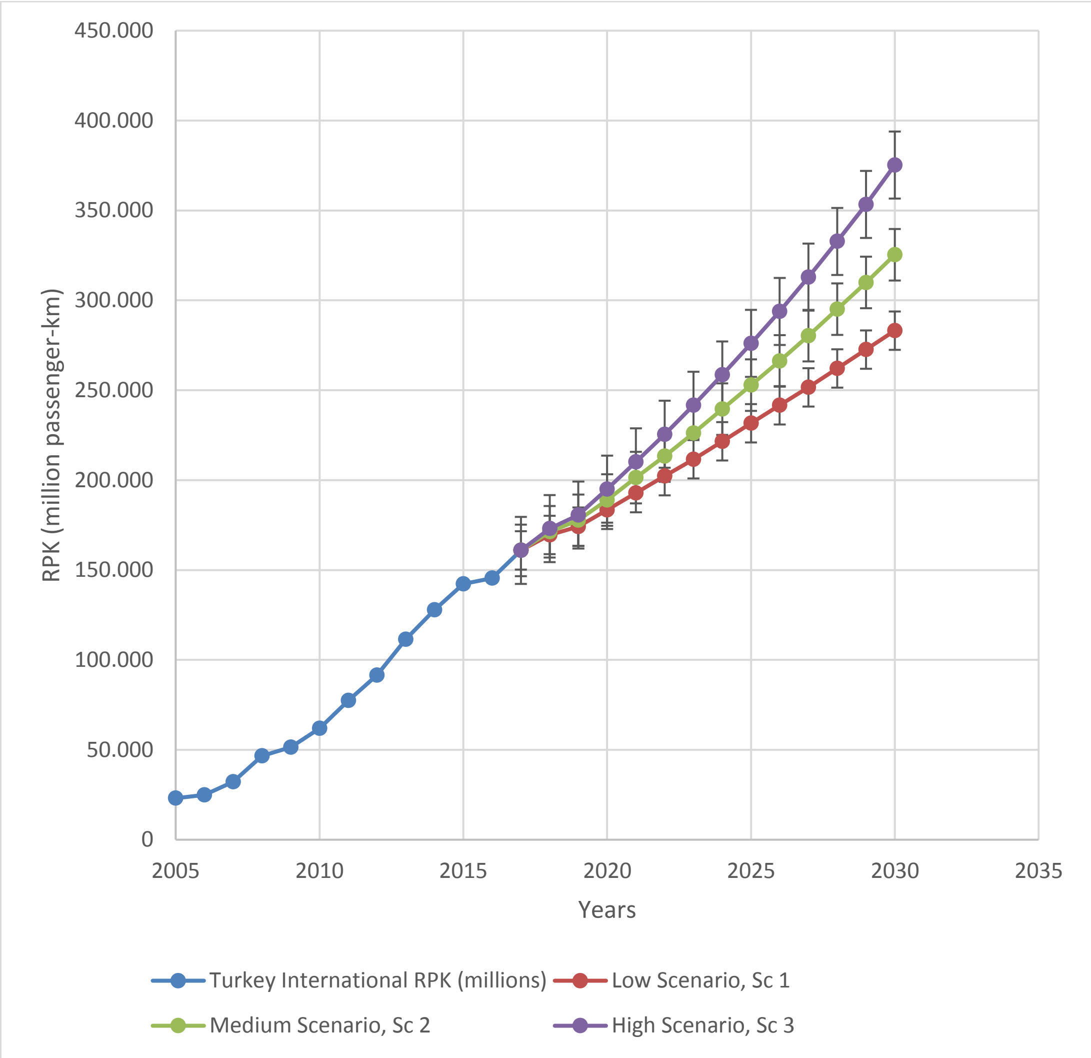

Figure 5.3 Air passenger traffic forecast results under different scenarios

Based on the forecast reports published by industry and international organizations, benchmarking analysis is conducted. The results obtained from the air passenger traffic model is compared with the industry forecasts. Thus, the predictions made for the world average are also considered under benchmarking analysis. Table 5.12 summarizes the forecasted CAGR values by different organizations (Airbus, 2018;

Boeing, 2018; Embraer, 2018; ICAO, 2016). Also the findings of this thesis also demonstrated at the lowest row of the table.

Table 5.12 CAGR values forecasted by different organizations

Predictor	Compound Annual Growth Rates (CAGR) of Passenger Traffic (%)		Forecast Period
	Intra-Europe	World Average	
ICAO	2.5	4.6	2016-2032
Boeing	3.6	4.7	2018-2037
Airbus	3.3	4.4	2018-2037
Embraer	3.7	4.5	2018-2037
This Study	4.6 -6.7		2018-2030

When the results are compared with the industry's and international organizations' forecasts, it seems that the results obtained in this thesis are fairly similar to the results of the other studies. However, it is obvious that growth rate expectations for Europe are well below the air passenger traffic growth of Turkey. On the other hand, keeping in the mind that Turkey's tremendous growth performance in aviation sector between 2005 and 2017, even under the lowest scenario (i.e. Scenario 1) it is expected for Turkey to grow higher than world average where the minimum world average growth is forecasted approximately as 4.4% and Turkey's 4.6% under lowest scenario.
In addition to that, as demonstrated by historical performance which is equal to annual 15% growth in RPK from 2005 to 2017, it is quite normal for Turkey to experience air passenger traffic growth above the world average under scenarios developed in this thesis. However, the results of this study shows that the growth trend of Turkey is going to slow down as the sector approaches the stages of reaching saturation.

5.3. Fuel Demand Forecast Results

In this section estimated results fuel demand of Turkey for international flights are given. Nine different results are presented based on the different scenario combinations. Table 5.13 summarizes the combination of scenarios studied for the fuel demand forecast.

Table 5.13 Fuel demand scenario combinations

Air Passenger Traffic Forecast Scenario	Fuel Intensity Improvement Scenario	Fuel Demand Forecast Scenario Indicator
Scenario 1	Sc L	Sc 1L
	Sc M	Sc 1M
	Sc H	Sc 1H
Scenario 2	Sc L	Sc 2L
	Sc M	Sc 2M
	Sc H	Sc 2H
Scenario 3	Sc L	Sc 3L
	Sc M	Sc 3M
	Sc H	Sc 3H

While calculating the fuel demand, fuel intensity approach is used in which fuel intensity is expressed as tons of fuel consumed per millions of air passenger traffic (RPK). For the calculation of fuel demand, Equation 7 provided in Chapter 4.2 is utilized.

In order to apply the scenarios fuel intensity calculated for 2017 in Section 4.4.5 and shown in the Table 4.7 is selected as the base year for the calculations. To recall, according to the Table 4.7, fuel intensity data of year 2017 is calculated as 32.1 tons of fuel per million RPK performed.

After obtaining fuel intensity data for the base year, fuel intensity improvement assumptions under each scenario are applied. The fuel intensity values estimated for different scenarios are presented under Section 4.6.1, 4.6.2 and 4.6.3..

5.3.1. Results of Scenario 1L

Scenario indicated as Sc 1L is the combination of Scenario 1 for the air passenger forecast and Scenario Low for the fuel intensity improvement. Firstly, the fuel intensity values shown under Section 4.6.1 for 2018-2030 are estimated with annual 1% fuel intensity improvement assumption. Then the intensity values shown in Table 4.12 are multiplied by the results of Scenario 1 of the air passenger traffic forecast presented in Table 5.7. The results are shown in the Table 5.14.

Table 5.14 Sc 1L model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	169,503	31.78	5,386,425
2019	174,132	31.46	5,478,197
2020	183,478	31.15	5,714,509
2021	192,774	30.83	5,944,006
2022	202,209	30.53	6,172,559
2023	211,613	30.22	6,395,012
2024	221,603	29.92	6,629,956
2025	231,631	29.62	6,860,693
2026	241,629	29.32	7,085,245
2027	251,596	29.03	7,303,724
2028	262,119	28.74	7,533,101
2029	272,610	28.45	7,756,281
2030	283,140	28.17	7,975,319

5.3.2. Results of Scenario 1M

Scenario indicated as Sc 1M is the combination of Scenario 1 for the air passenger forecast and Scenario Medium for the fuel intensity improvement. Firstly, the fuel intensity values shown under Section 4.6.3 for 2018-2030 are estimated with annual 1.5% fuel intensity improvement assumption and then the intensity values obtained and shown in Table 4.13 are multiplied by the results of Scenario 1 of the air passenger traffic forecast. The results are shown in the Table 5.15.

Table 5.15 Sc1M model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	169,503	31.62	5,359,221
2019	174,132	31.14	5,423,002
2020	183,478	30.68	5,628,362
2021	192,774	30.22	5,824,831
2022	202,209	29.76	6,018,252
2023	211,613	29.32	6,203,654
2024	221,603	28.88	6,399,085

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2025	231,631	28.44	6,588,344
2026	241,629	28.02	6,769,619
2027	251,596	27.60	6,943,120
2028	262,119	27.18	7,125,005
2029	272,610	26.77	7,299,044
2030	283,140	26.37	7,467,265

5.3.3. Results of Scenario 1H

Scenario indicated as Sc 1H is the combination of Scenario 1 for the air passenger forecast and Scenario High for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 2.5% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 1 of the air passenger traffic forecast. The results are shown in the Table 5.16.

This scenario represents the lowest air passenger traffic growth and highest fuel intensity improvement. Thus, the fuel demand found under that scenario is the minimum fuel demand of Turkey for international civil aviation activities through 2030 which is nearly equal to 6.5 million tons.

Table 5.16 Sc1H model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	169,503	31.30	5,304,813
2019	174,132	30.51	5,313,449
2020	183,478	29.75	5,458,675
2021	192,774	29.01	5,591,868
2022	202,209	28.28	5,718,898
2023	211,613	27.58	5,835,229
2024	221,603	26.89	5,957,947
2025	231,631	26.21	6,071,882
2026	241,629	25.56	6,175,608
2027	251,596	24.92	6,269,581

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2028	262,119	24.30	6,368,504
2029	272,610	23.69	6,457,830
2030	283,140	23.10	6,539,590

5.3.4. Results of Scenario 2L

Scenario indicated as Sc 2L is the combination of Scenario 2 for the air passenger forecast and Scenario Low for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 1% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 2 of the air passenger traffic forecast. The results are shown in the Table 5.17.

Table 5.17 Sc2L model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	171,288	31.78	5,443,165
2019	177,653	31.46	5,588,968
2020	188,927	31.15	5,884,212
2021	201,406	30.83	6,210,135
2022	213,405	30.53	6,514,311
2023	226,110	30.22	6,833,117
2024	239,489	29.92	7,165,090
2025	252,858	29.62	7,489,390
2026	266,314	29.32	7,809,074
2027	280,376	29.03	8,139,205
2028	295,113	28.74	8,481,352
2029	309,958	28.45	8,818,894
2030	325,359	28.17	9,164,496

5.3.5. Results of Scenario 2M

Scenario indicated as Sc 2M is the combination of Scenario 2 for the air passenger forecast and Scenario Medium for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 1.5% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 2 of the air passenger traffic forecast. The results are shown in the Table 5.18.

Table 5.18 Sc2M model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	171,288	31.62	5,415,674
2019	177,653	31.14	5,532,657
2020	188,927	30.68	5,795,507
2021	201,406	30.22	6,085,625
2022	213,405	29.76	6,351,462
2023	226,110	29.32	6,628,649
2024	239,489	28.88	6,915,585
2025	252,858	28.44	7,192,084
2026	266,314	28.02	7,461,203
2027	280,376	27.60	7,737,352
2028	295,113	27.18	8,021,886
2029	309,958	26.77	8,299,015
2030	325,359	26.37	8,580,687

5.3.6. Results of Scenario 2H

Scenario indicated as Sc 2H is the combination of Scenario 2 for the air passenger forecast and Scenario High for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 2.5% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 2 of the air passenger traffic forecast. The results are shown in the Table 5.19.

Table 5.19 Sc2H model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	171,288	31.30	5,360,693
2019	177,653	30.51	5,420,889
2020	188,927	29.75	5,620,780
2021	201,406	29.01	5,842,231
2022	213,405	28.28	6,035,533
2023	226,110	27.58	6,234,984
2024	239,489	26.89	6,438,839
2025	252,858	26.21	6,628,295
2026	266,314	25.56	6,806,507
2027	280,376	24.92	6,986,766
2028	295,113	24.30	7,170,158
2029	309,958	23.69	7,342,554
2030	325,359	23.10	7,514,690

5.3.7. Results of Scenario 3L

Scenario indicated as Sc 3L is the combination of Scenario 3 for the air passenger forecast and Scenario Low for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 1% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 3 of the air passenger traffic forecast. The results are shown in the Table 5.20.

This scenario represents the highest air traffic passenger growth and lowest fuel intensity improvement. Thus, the fuel demand found under that scenario is the maximum fuel demand of Turkey for international civil aviation activities through 2030 which is nearly equal to 10.6 million tons.

Table 5.20 Sc3L model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	173,049	31.78	5,499,106
2019	180,585	31.46	5,681,218

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2020	194,995	31.15	6,073,191
2021	210,180	30.83	6,480,695
2022	225,534	30.53	6,884,581
2023	241,636	30.22	7,302,340
2024	258,497	29.92	7,733,759
2025	276,079	29.62	8,177,184
2026	293,827	29.32	8,615,835
2027	312,939	29.03	9,084,490
2028	332,763	28.74	9,563,375
2029	353,362	28.45	10,053,809
2030	375,270	28.17	10,570,365

5.3.8. Results of Scenario 3M

Scenario indicated as Sc 3M is the combination of Scenario 3 for the air passenger forecast and Scenario Medium for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 1.5% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 3 of the air passenger traffic forecast.

Table 5.21 Sc3M model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	173,049	31.62	5,471,333
2019	180,585	31.14	5,623,977
2020	194,995	30.68	5,981,636
2021	210,180	30.22	6,350,761
2022	225,534	29.76	6,712,475
2023	241,636	29.32	7,083,832
2024	258,497	28.88	7,464,451
2025	276,079	28.44	7,852,575
2026	293,827	28.02	8,232,026
2027	312,939	27.60	8,635,966
2028	332,763	27.18	9,045,291

2029	353,362	26.77	9,461,131
2030	375,270	26.37	9,896,997

5.3.9. Results of Scenario 3H

Scenario indicated as Sc 3H is the combination of Scenario 3 for the air passenger forecast and Scenario High for the fuel intensity improvement. Firstly, the fuel intensity values for 2018-2030 are calculated with annual 2.5% fuel intensity improvement assumption and then the intensity values obtained are multiplied by the results of Scenario 3 of the air passenger traffic forecast. The results are shown in the Table 5.22.

Table 5.22 Sc3H model results

Years	International RPK (millions)	Fuel Intensity (tons of fuel/million RPK)	Fuel Demand (tons)
2018	173,049	31.30	5,415,786
2019	180,585	30.51	5,510,364
2020	194,995	29.75	5,801,298
2021	210,180	29.01	6,096,763
2022	225,534	28.28	6,378,589
2023	241,636	27.58	6,663,134
2024	258,497	26.89	6,949,868
2025	276,079	26.21	7,237,010
2026	293,827	25.56	7,509,693
2027	312,939	24.92	7,798,207
2028	332,763	24.30	8,084,903
2029	353,362	23.69	8,370,737
2030	375,270	23.10	8,667,472

5.3.10. Summary of Fuel Demand Forecast Results

Figure 5.4 visualizes the summary of the nine different fuel demand values of each scenario defined. The results showed that fuel demand of Turkey will range from 6.5 to 10.6 million tons.

According to the results, the highest fuel demand is obtained under Scenario 3L in which high air traffic growth rate and low fuel intensity assumption is made. On the other hand, as expected, the lowest fuel demand is found under the Scenario 1H where lowest air passenger traffic growth assumption is combined with highest fuel intensity improvement assumption.

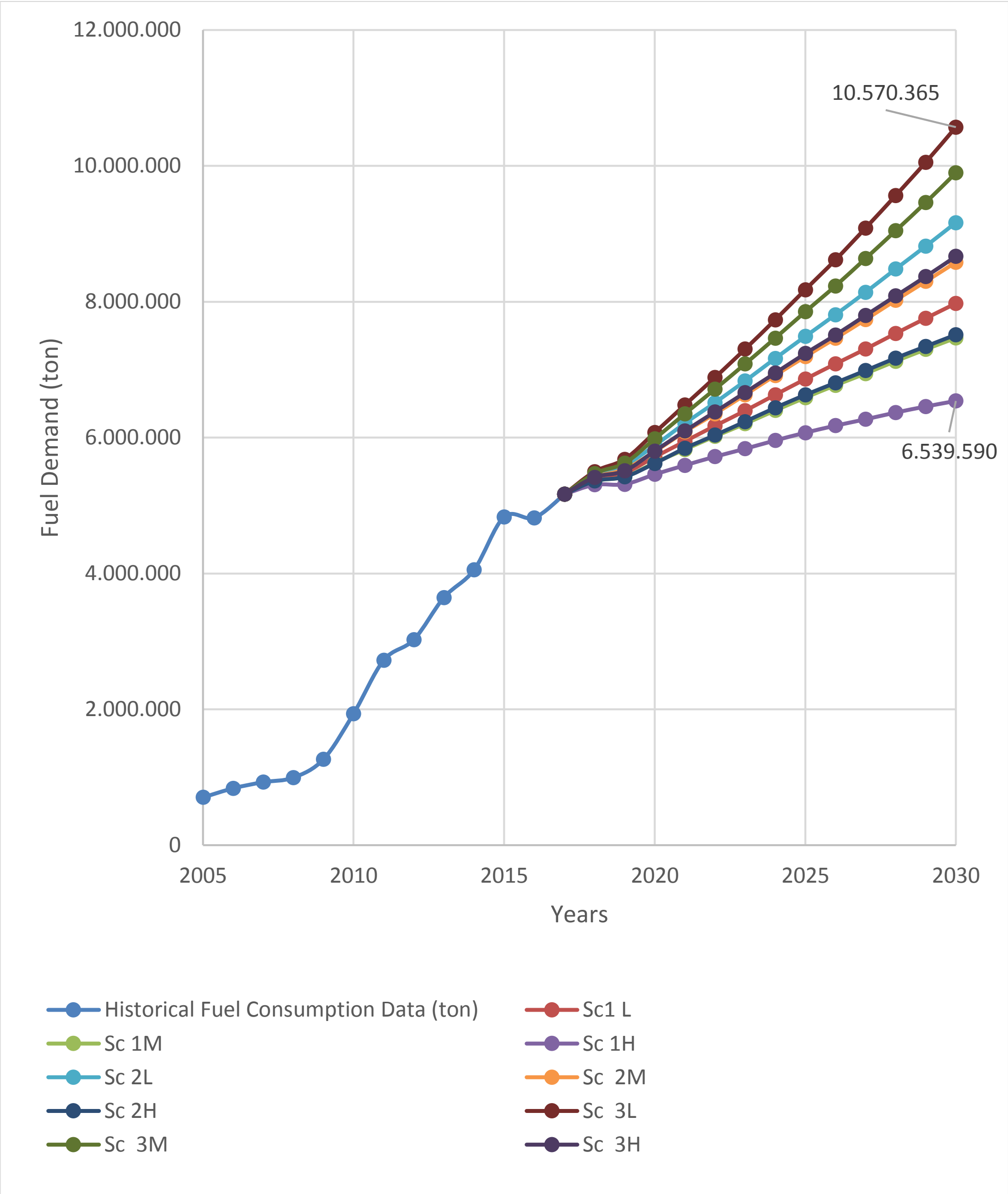

Figure 5.4 Fuel demand results under different scenarios

As mentioned in Chapter 3.2 in literature there are many studies forecasting jet fuel demand on country, regional, or world-wide basis. However, the number of work that has been done in the case of Turkey is very limited. Thus, jet fuel demand forecast comparison can only be done with one study conducted by Melikoğlu in 2016. The study forecasts jet fuel and bio-based fuel demand of Turkey between 2013 and 2023. Melikoğlu projected that, in 2023 Turkey's jet fuel demand will be between 3.4 Mton and 6.3 Mton on mass basis (Melikoğlu, 2016).

In this thesis for 2023 it is forecasted that jet fuel demand will be between 5.8 Mton and 7.3 Mton under optimistic and pessimistic scenarios, respectively. In this thesis, jet fuel demand of Turkey is forecasted relatively higher. The higher estimations are mainly due to the use of different methodologies used in the studies and the models that are being built on different assumptions. Another reason can be due to the difference in data set which is incorporated into the models that are utilized in the studies. Melikoğlu generates fuel demand forecast for 2013-2023 period with use historical of jet fuel consumption data obtained from United States Energy Information Administration database whereas in this thesis fuel consumption values are obtained from the DGCA of Turkey which are directly obtained from the aeroplane operators registered to Turkey. The historical jet fuel consumption data used by Melikoğlu is relatively lower than the fuel consumption data provided by Turkish DGCA so that accordingly the CO_2 emissions estimated are relatively lower.

However, both of the results are showing that fuel demand of the Turkey's aviation sector will continuously increase in future, despite substantial improvement achieved on aircraft technology in terms of fuel efficiency, technological improvements alone will not be sufficient to hold down the growth of fuel demand.

5.4. CO_2 Emission Results

In this chapter CO_2 emissions resulting from the fuel demand scenarios of Turkey for international flights are calculated and results are shown. Likewise in fuel demand scenarios, the results of the nine different scenario are provided.

For the calculation of CO_2 emissions, as explained in Chapter 3 of this thesis, Tier 1 method of the IPCC is used since only fuel demand data is available. As already mentioned in Chapter 4.4 the aeroplane operators registered to Turkey are using only jet kerosene for their flights. Thus, the emission specific factor of jet kerosene which is equal to 3.153 ton CO_2 per ton fuel consumed provided in Chapter 4.4 are used for the calculations.

5.4.1. Results of Scenario 1L

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 1L which is the combination of assumptions below:

- low air traffic growth and
- low fuel intensity improvement.

Jet fuel demand estimated under 1L scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.23. Under this scenario it is found out that CO_2 emissions originating from the international civil aviation activities is going to increase approximately 54% with respect to 2017 levels and increase from 16.98 Mton to 25.15 Mton from 2018 to 2030.

Table 5.23 CO2 Emission under Sc1L

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	16.98
2019	17.27
2020	18.02
2021	18.74
2022	19.46
2023	20.16
2024	20.90
2025	21.63
2026	22.34
2027	23.03
2028	23.75
2029	24.46
2030	25.15

5.4.2. Results of Scenario 1M

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 1M which is the combination of assumptions below:

- low air traffic growth and
- medium fuel intensity.

Jet fuel demand estimated under 1M scenario is multiplied with the fuel specific emission factor of jet kerosene which is 3.153 tons of CO_2 per tons of jet kerosene consumed. The results are shown in the Table 5.24 below.

Table 5.24 CO2 Emission under Sc1M

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	16.90
2019	17.10
2020	17.75
2021	18.37
2022	18.98
2023	19.56
2024	20.18
2025	20.77
2026	21.34
2027	21.89
2028	22.47
2029	23.01
2030	23.54

5.4.3. Results of Scenario 1H

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 1H which is the combination of assumptions below:

- low air traffic growth and
- high fuel intensity.

The jet fuel demand estimated under 1H scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.25. This scenario represents the most optimistic scenario under this thesis. Thus, the CO_2 emissions calculated under that scenario is showing the minimum CO_2 emission of Turkey for international civil aviation activities through 2030 which is forecasted as 20.62 Mton. The result are showing that under low growth of air traffic and high improvement of fuel intensity, international CO_2 emissions of Turkey will be nearly 1.3 times of the emissions recorded in 2017 and reached up to 20.62 Mton in 2030.

Table 5.25 CO2 Emission under Sc1H

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	16.73
2019	16.75
2020	17.21
2021	17.63
2022	18.03
2023	18.40
2024	18.79
2025	19.14
2026	19.47
2027	19.77
2028	20.08
2029	20.36
2030	20.62

5.4.4. Results of Scenario 2L

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 2L which is the combination of assumptions below:

- medium air traffic growth and
- low fuel intensity.

The jet fuel demand estimated under 2L scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.26. Under Scenario

2L, it is forecasted that CO_2 emissions will increase around 77% compared to 2017 levels and reached to 28.90 Mton in 2030.

Table 5.26 CO2 Emission under Sc2L

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	17.16
2019	17.62
2020	18.55
2021	19.58
2022	20.54
2023	21.54
2024	22.59
2025	23.61
2026	24.62
2027	25.66
2028	26.74
2029	27.81
2030	28.90

5.4.5. Results of Scenario 2M

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 2M which is the combination of assumptions below:

- medium air traffic growth and
- medium fuel intensity.

The jet fuel demand estimated under 2M scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.27. Despite different assumptions, the results for CO_2 emissions under Scenario 2M are very close to the Scenario 3H. This means air traffic growth and fuel intensity assumptions are balancing each other in these two scenarios. Under Sc 2M, it is estimated that international CO_2 emissions of Turkey will increase from 17.08 Mton to 27.05 Mton in 2018-2030 time interval.

Table 5.27 CO2 Emission under Sc2M

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	17.08
2019	17.44
2020	18.27
2021	19.19
2022	20.03
2023	20.90
2024	21.80
2025	22.68
2026	23.53
2027	24.40
2028	25.29
2029	26.17
2030	27.05

5.4.6. Results of Scenario 2H

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 2H which is the combination of assumptions below:

- medium air traffic growth and
- high fuel intensity.

The jet fuel demand estimated under 2H scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.28.

Table 5.28 CO2 Emission under Sc2H

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	16.90
2019	17.09
2020	17.72
2021	18.42
2022	19.03
2023	19.66
2024	20.30
2025	20.90

Years	CO_2 Emissions (Mton)
2026	21.46
2027	22.03
2028	22.61
2029	23.15
2030	23.69

5.4.7. Results of Scenario 3L

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 3L which is the combination of assumptions below:

- high air traffic growth and
- low fuel intensity.

The jet fuel demand estimated under 3L scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.29. This scenario represents the worst-case scenario under this thesis. Thus, the CO_2 emissions calculated under that scenario is showing the maximum CO_2 emission of Turkey for international civil aviation activities through 2030 which is forecasted as 33.33 Mton.

Table 5.29 CO2 Emission under Sc3L

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	17.34
2019	17.91
2020	19.15
2021	20.43
2022	21.71
2023	23.02
2024	24.38
2025	25.78
2026	27.17
2027	28.64
2028	30.15
2029	31.70
2030	33.33

5.4.8. Results of Scenario 3M

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 3M which is the combination of assumptions below:

- high air traffic growth and
- medium fuel intensity.

The jet fuel demand estimated under 3M scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.30. Under Scenario 3M, it is forecasted that CO_2 emissions will be 17.25 Mton and 31.21 Mton in 2018 and 2030 respectively. This scenario implies that the effect of the air traffic growth on the CO_2 emissions is much stronger than the effect of fuel intensity improvement. CO_2 emissions are estimated to increase around 92% compared to 2017 levels under Scenario 3M.

Table 5.30 CO2 Emission under Sc3M

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	17.25
2019	17.73
2020	18.86
2021	20.02
2022	21.16
2023	22.34
2024	23.54
2025	24.76
2026	25.96
2027	27.23
2028	28.52
2029	29.83
2030	31.21

5.4.9. Results of Scenario 3H

CO_2 emissions are calculated based on the jet fuel demand result of the Scenario 3H which is the combination of assumptions :

- high air traffic growth and
- high fuel intensity.

The jet fuel demand estimated under 3H scenario is multiplied with the fuel specific emission factor of jet kerosene and results are shown in Table 5.31. This scenario also indicates that even if the highest value of fuel intensity improvement would maintained, it will not be sufficient to balance the effect of air passenger traffic growth on the emissions. In other words, despite sustaining higher levels of fuel efficiency the increment of the CO_2 emissions are highly dependent to air passenger traffic growth. Under Scenario 3H, it forecasted that the emissions are going to reach 27.33 Mton in 2030 which is nearly above 68% than 2017 levels.

Table 5.31 CO2 Emission under Sc3H

Years	CO_2 Emissions (Mton)
2017	**16.29**
2018	17.08
2019	17.37
2020	18.29
2021	19.22
2022	20.11
2023	21.01
2024	21.91
2025	22.82
2026	23.68
2027	24.59
2028	25.49
2029	26.39
2030	27.33

5.4.10. Error Propagation

In order to calculate the overall uncertainty the error propagation approach which is explained in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories under Chapter 3 is utilized (IPCC, 2006). The first uncertainty occurs due to the regression model developed for air passenger traffic estimation and the second uncertainty occurs due to emission conversion factors used to calculate CO_2 emissions.

In order to find out overall uncertainty firstly the errors in the scenarios of the regression model is calcutaed as a percentage error and shown in the Table 5.32. Then the uncertainty coming from the emission conversion factor is obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories as ±5% (IPCC, 2006).

Table 5.32 Uncertanities in regression model scenarios as percentage

Years	SC 1 (±)	SC 2 (±)	SC 3 (±)
2018	8%	7%	7%
2019	9%	8%	8%
2020	9%	8%	7%
2021	9%	7%	6%
2022	9%	7%	6%
2023	9%	7%	5%
2024	8%	6%	5%
2025	8%	6%	5%
2026	8%	5%	6%
2027	8%	5%	7%
2028	7%	5%	8%
2029	7%	6%	10%
2030	6%	6%	11%

Since multiplication process is used in the calculation of emissions within the scope of this thesis, in order to combine uncertainities the equation provided to estimate total uncertanity is used.

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2} \qquad (9)$$

where;

U_{total} = Total uncertainty, the percentage uncertainty in the product of the quantities expressed as a percentage

U_i = the percentage uncertainty associated with each of the quantities

After appliying the Formula (9) total uncertainty is calculated for each scenario. The total uncertanities calculated for each scenario under this theiss is provided in the Table 5.33.

Table 5.33 Total uncertanities under each scenario

Years	SC 1L (±)	SC 1M (±)	SC 1 H (±)	SC 2L (±)	SC 2M (±)	SC 2H (±)	SC 3L (±)	SC 3M (±)	SC 3H (±)
2018	9%	9%	9%	9%	9%	9%	9%	9%	9%
2019	10%	10%	10%	10%	10%	10%	9%	9%	9%
2020	10%	10%	10%	9%	9%	9%	9%	9%	9%
2021	10%	10%	10%	9%	9%	9%	8%	8%	8%
2022	10%	10%	10%	9%	9%	9%	8%	8%	8%
2023	10%	10%	10%	8%	8%	8%	7%	7%	7%
2024	10%	10%	10%	8%	8%	8%	7%	7%	7%
2025	10%	10%	10%	8%	8%	8%	7%	7%	7%
2026	9%	9%	9%	7%	7%	7%	8%	8%	8%
2027	9%	9%	9%	7%	7%	7%	9%	9%	9%
2028	9%	9%	9%	7%	7%	7%	10%	10%	10%
2029	8%	8%	8%	8%	8%	8%	11%	11%	11%
2030	8%	8%	8%	8%	8%	8%	12%	12%	12%

5.4.11. Summary of CO_2 Emissions

Figure 5.5 visualizes the summary of the nine different CO_2 emission values of each scenario defined. The results showed that the emissions originating from international civil aviation activities of Turkey will range from 20.62 to 33.33 million tons.

According to the results, the highest CO_2 emission is obtained under Scenario 3L whereas the lowest CO_2 emission is found under the Scenario 1H where lowest air passenger traffic growth assumption is combined with highest fuel intensity improvement assumption.

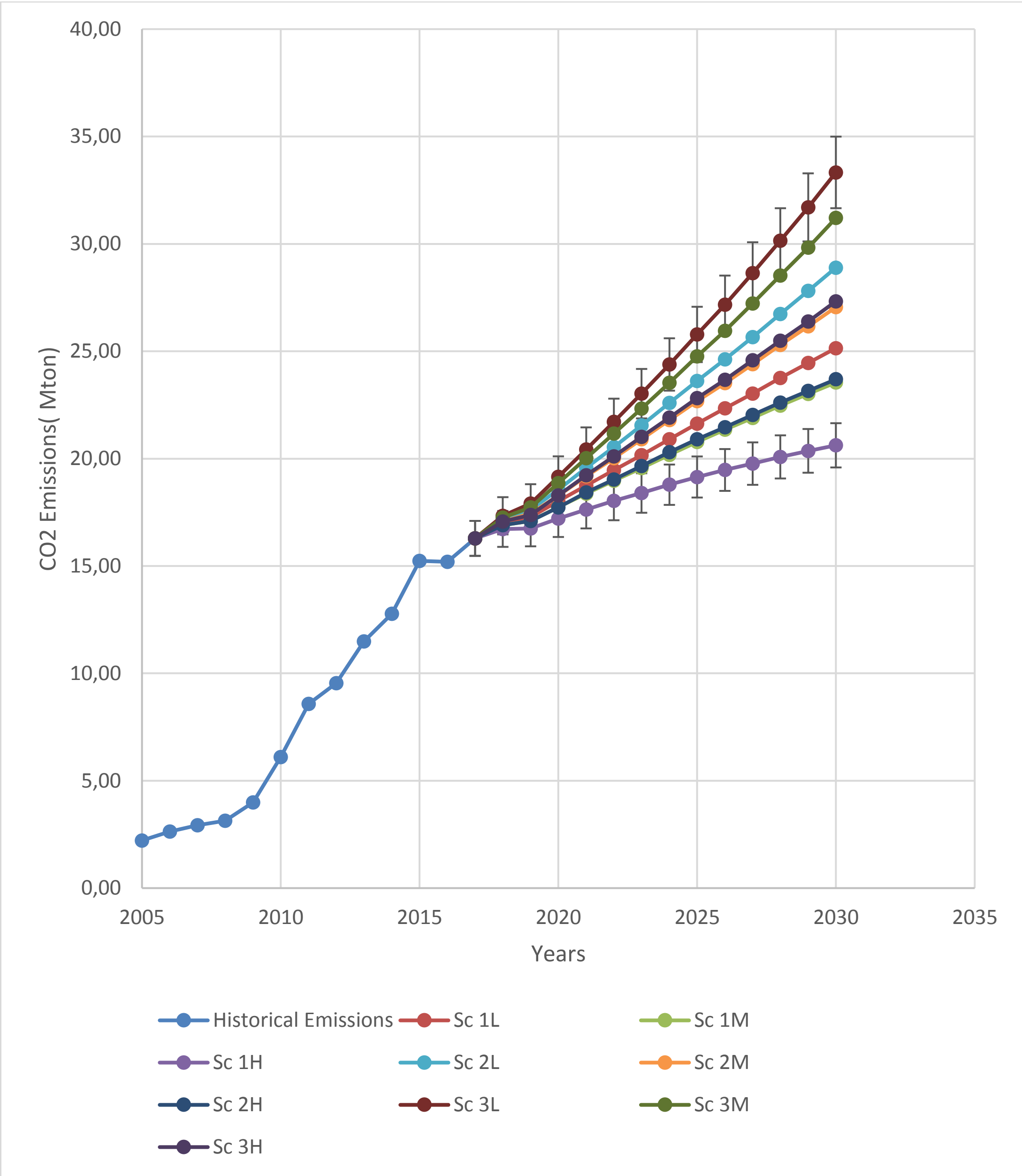

Figure 5.5 CO2 emission results under different scenarios

Since there is no study in literature that is especially conducted for Turkey to forecast CO_2 emissions, benchmarking analysis can be only done with the National Inventory Report of the Turkey published in April 2019. This report includes the 1990-2017 CO_2 emissions originating from international aviation activities; however the latest data published in this report is for year 2017. For 2017, the report indicated that 154,053 TJ of aviation fuel is consumed (which is equal to 3.5 Mtons of jet fuel in terms of mass when heating value of the fuel is taken as 44.65 MJ/kg). As a result of this consumption, with IPCC Tier 1 calculation methodology CO_2 emissions of the international aviation is calculated as 11.11 Mtons for 2017 (Turkish Statistical Institute, 2019). On the other hand, in this thesis the international jet fuel consumption data provided by Turkish DGCA for 2017 which is equal to 5.3 Mtons of jet fuel is used for the calculation of the base year emissions, thus despite using the exactly same CO_2 calculation methodology with the National Inventory Report of Turkey, international CO_2 emissions of 2017 is calculated as 16.29 Mtons in this thesis. Because of the difference in the raw jet fuel consumption data there is a slight difference in the results.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Today aviation sector significant role in the economic development of countries by connecting them for business, tourism, trade, defense, and humanitarian purposes. As demand for the air transportation increases unavoidably CO_2 emissions generated by the sector increases. Civil aviation contributes global emissions in tiny portions; yet CO_2 emissions related to aviation activities showing much faster growth trend than other industry.

On the other hand, like in any other developing country civil aviation activities in Turkey are increasing sharply since 2000s in terms of air traffic. Thus, the CO_2 emissions of the sector is increasing proportionally and causing adverse effects on the climate change. Yet, Turkey does not have any guiding forecast study to be used in decision-making mechanisms in order to ensure sustainable growth of the sector by following environmental protection measures taken locally or regionally without restricting aviation activities.

So in this study, it is aimed to develop a methodlogy that is cabaple of estimating estimate future CO_2 emissions of a country which experiences sharp growth in aviation sector, and the key factors that have causal effect on the air traffic growth is investigated. This thesis offers methodlogy that helps other fast growing countries to predict their future air passenger growth and corresponding fuel demand thus CO_2 emissons.

In addition to that this is the first comprehensive study that forecasts international air traffic demand of Turkish civil aviation sector, determines the corresponding fuel demand of Turkish aeroplane operators for their international flights, and calculates the growth trend of associated CO_2 emissions. So the results of this study can be utilized by academia, aviation industry, policy makers and regulators as a guide. The findings of this study can be used as a base dataset for other studies regarding to environmental management of the aviation sector.

The main conclusions that can be drawn from this study are explained in the following sections; and the recommendations are provided at the end of the chapter.

6.1. Air Passenger Traffic Demand

As mentioned, air passenger model is run under three different scenarios representing low, medium, and high cases. The low scenario which is indicated as Scenario 1 showed that even in the lowest case Turkey's air traffic demand will increase to 283,140 million revenue passenger kilometers in 2030. The CAGR of Turkey' air passenger traffic growth is estimated as 4.6% under this scenario.

The medium scenario which is indicated Scenario 2 under this thesis showed that Turkey's air traffic demand will increase to 325,359 million revenue passenger kilometers in 2030, which doubles the 2017 levels. Under Scenario 2 the compound annual growth rate (CAGR) of RPK of Turkey is estimated as 5.8%.

Lastly, Scenario 3 of the air passenger traffic demand, the highest scenario, showed that RPK of Turkey will increase approximately 133% and reaches from 160,918 million passenger kilometers to 375,270 million passenger kilometers from 2017 to 2030. Under Scenario 3, CAGR of the air passenger traffic growth is forecasted as 6.7%. Table 6.1 summarizes the forecasted compound annual growth rates of the air passenger traffic model established under this study.

Table 6.1 CAGR values under different scenarios

Scenario	Compound Annual Growth Rate(CAGR) between 2018-2030
Scenario 1 (Low)	4.6%
Scenario 2 (Medium)	5.8%
Scenario 3 (High)	6.7%

6.2. Fuel Demand

Results regarding to fuel demand until 2030 demonstrates that fuel demand of Turkey is ranging from 6.5 Mton to 10.6 Mton of jet kerosene for the pessimistic and optimistic scenarios respectively.

The results showed that minimum fuel demand would occur under Scenario 1H where low air traffic growth assumptions are combined with lowest fuel intensity improvements. And the highest fuel demand is obtained under Scenario 3H where high air traffic growth assumptions are combined with high fuel intensity improvement.

Results regarding to fuel demand projections revealed an average annual increase in the order of 1.6% and 5.4% for the most optimistic scenario and pessimistic scenario respectively. On the other hand the average increase observed in jet fuel demand under other scenarios is varying between 2.6% and 4.9%.

6.3. CO_2 Emissions

According to the results of Scenario 1H, which is the most optimistic scenario; CO_2 emissions from the international civil aviation activities of Turkey will increase to 20.62 Mton in 2030. Even in the most optimistic case, CO_2 emissions of the international civil aviation of Turkey are tend to increase approximately 26% compared to 2017 levels.

On the other hand, the results of the Scenario 3L showed that CO_2 emissions originating from international flights of Turkey will increase with an average annual rate of 5.4% over 13 years and reached to 33.33 Mton of CO_2 in 2030. This means, CO_2 emissions of Turkish international civil aviation are expected to double in 2030 compared to 2017 levels.

The results of this study demonstrated that the CO_2 emissions of the civil aviation sector continues to be one of the fastest growing source of the emissions in Turkey. Moreover, it is expected for civil aviation sector to take a large share of the Turkey's carbon budget in the near future.

6.4. Recommendations on Future Research Needs

Based on the results obtained in this thesis, couple of policy recommendations can be proposed for the control of the international CO_2 emissions of Turkey;

- Incorporation of measures regarding to air traffic management, route optimization, and operational management into Turkish civil aviation environmental protection policies,
- Estimation of domestic emissions of Turkey based on IPCC Tier 2 or Tier 3 methodologies,
- Encouragement of Turkish aeroplane operators to invest on new technology aircrafts which are more fuel efficient,
- Introduction of sustainable aviation fuels which can achieve net greenhouse gas reductions on a life cycle basis compared to conventional jet fuel into Turkish civil aviation environmental protection policies once they are produced at reasonable quantities and prices all around the world ,
- Incorporation of ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) into national legislation which is global market based carbon offsetting mechanism enabling aeroplane operators to neutralize their emissions via purchasing carbon credits from the carbon markets in the world.

However, it should be noted that policies to be introduced to the national legislation should ensure the sustainable growth of the sector without restricting the demand for the air transport in Turkey. Thus, comprehensive cost and environmental benefit analysis should be done before making a decision.

In order to evolve current knowledge on the CO_2 emissions, fuel demand. and air passenger traffic projections of international civil aviation sector in Turkey this study can be used as a starting point to for further studies which focuses on;

- forecast of domestic CO_2 emissions of Turkey and impact of CO_2 emissions on local air quality,

- effect of route optimization on CO_2 emissions and its corresponding economic and environmental impacts,
- detailed assessment of introduction of combinations of measures into Turkish civil aviation environmental protection policies for emission mitigation,
- effect of use of sustainable aviation fuels on emissions of Turkish air carriers and Turkey's potential to produce bio-based sustainable aviation fuels,
- economic impacts of introducing market based mechanisms in Turkey and environmental benefits in terms of emission reduction,
- assessment on the supply and demand balance of Turkish voluntary carbon markets and aviation sector's carbon credit demand for CORSIA,
- assessment of the impact of inclusion of the aviation sector into Turkey's Intended Nationally Determined Contribution (INDC) towards achieving the ultimate objective of the United Nations Framework Convention on Climate Change and
- simulating the construction of carbon market and a nationwide registry system in Turkey and incorporation of aviation sector into the market.

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APPENDICES

A. Permission for Fuel Data

T.C.
ULAŞTIRMA VE ALTYAPI BAKANLIĞI
Sivil Havacılık Genel Müdürlüğü

Sayı : 20443621-611.04-E.10682 31.05.2019

Konu : Veri Talebi

Sayın Deniz KAYMAK

İlgi : Deniz KAYMAK'ın 28.05.2019 tarihli başvurusu.

İlgi'de kayıtlı yazınız ile yüksek lisans öğrencisi olduğunuzu beyan ettiğiniz Orta Doğu Teknik Üniversitesi Fen Bilimleri Enstitüsü Çevre Mühendisliği Bölümünde yaptığınız tez çalışması için ülkemize ait havayollarının ulsulararası uçuşlarda kullandıkları toplam yakıt tüketimi verisine ihtiyacınız olduğu belirtilmiştir.

Konuyla ile ilgili 4982 sayılı Bilgi Edinme Hakkı Kanunu çerçevesinde talep ettiğiniz veriler Ek'te sunulmakla beraber, bu verilerin akademik çalışmanız dışında kullanılmaması, veri paylaşımında bulunduğu tezlerde ve bu tezlerden üretilen yayınlarda verilerin Genel Müdürlüğümüz tarafından havayolu ismi belirtilmeden toplam şeklinde sağlandığı mutlaka belirtilmelidir. Ayrıca, paylaşılan verilerin mahiyetini ve özelliğini bozan herhangi bir değişiklik yapılamayacağı, yapıldığı takdirde 4982 sayılı kanunun yaptırımlarına maruz kalınacağı hususunun dikkate alınmasını rica ederim.

e-imzalıdır
Sertan ALBUZ
Daire Başkan V.

Ek : Yakıt Tüketimi Verileri (1 sayfa)

Bilgi için:Ahmet Berkan KORKMAZ
Uzman
Telefon No:(312) 203 60 87

Yıllar	Uluslararası Uçuşlardan Kaynaklı Jet Yakıtı Tüketimi (ton)
2005	703,750
2006	836,798
2007	928,091
2008	994,277
2009	1,264,879
2010	1,936,212
2011	2,722,153
2012	3,025,424
2013	3,645,677
2014	4,052,756
2015	4,832,765
2016	4,819,823
2017	5,165,275