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CIVIL AVIATION CARBON DIOXIDE EMISSIONS IN CHINA

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ABSTRACT

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With the social and economic development, the civil aviation industry of China is experiencing rapid growth. This growth will lead to more CO_2 emissions. Carbon dioxide emissions and greenhouse effect are already serious problems especially in China, but also all over the world.

Civil aviation has brought environmental pollution in the context of improving social activity and economic growth. Because of civil aviation, the rapid increase of the total amount of air pollutants are also increasing, covering most of the cities in China especially in economically developed areas that have more pollution. Therefore the greenhouse gases generated by the aircrafts are an important reason for global warming in an increasing amount. The collection of data of the 2009 Chinese domestic and international routes is using a more accurate algorithm to calculate the 2009 Chinese civil aviation industry carbon dioxide emissions. As result from more accurate data of CO_2 emissions the role of CO_2 in the greenhouse effect will be understood better.

Key words
carbon dioxide, civil aviation, greenhouse effect, aviation fuels

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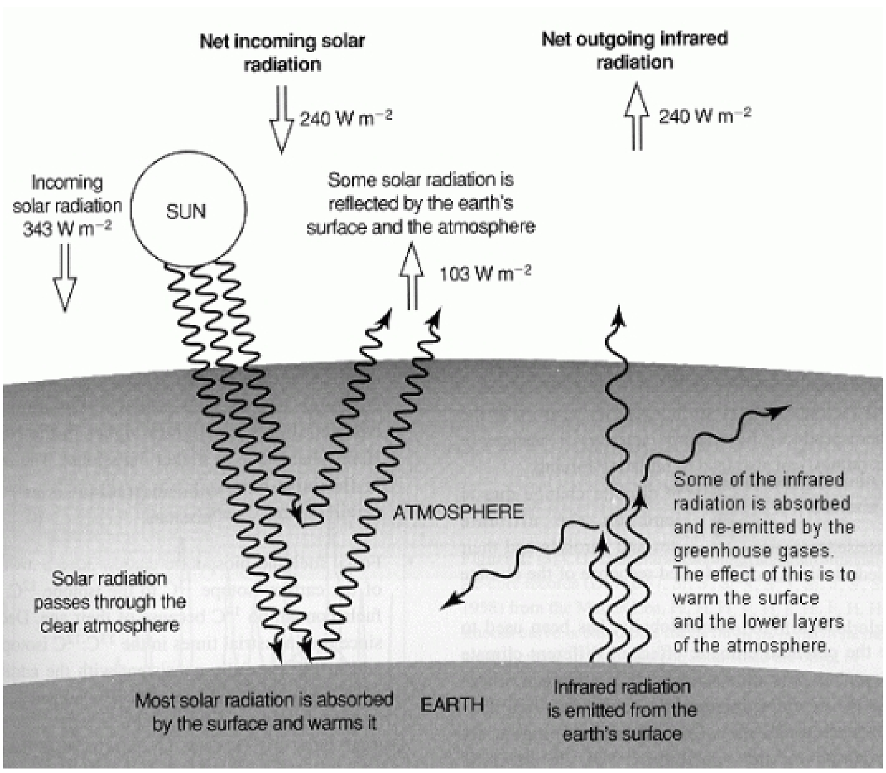
CONTENTS

1 INTRODUCTION

Greenhouse effect refers to a physical characteristic of Earth's atmosphere. If there is no atmosphere, the average temperature of Earth's surface is lower than -18℃, instead of the adequate 15℃ that it is thanks to the atmosphere. The temperature differences are due to greenhouse gases and infrared radiation from the gas, affecting the whole balance of power. In the current situation, the ground and the atmosphere absorb the solar radiation in the overall balance of the infrared radiation releases to outer space. However, due to greenhouse gases the absorption of infrared radiation is now larger than the amount of radiation that is released back into outer space, which makes Earth's surface temperature rise. This process is called the natural greenhouse effect. Due to human activities that are increasing the release of greenhouse gases, there is now more infrared radiation that is turning back to the ground and thereby strengthening the role of the greenhouse effect.



GRAPH1. Greenhouse Effect (Hong Kong observatory 2003.)

Graph 1 illustrates the global long-term radiative balance of the atmosphere. Net input of solar radiation must be balanced by net output of infrared radiation. About a third of incoming solar radiation is reflected and the remainder is mostly absorbed by the surface. Outgoing infrared radiation is absorbed by greenhouse gases and by clouds.

The aim of this thesis is to make greenhouse effect and the role of carbon dioxide in it more known, and also want to make people realize that their everyday decisions of transportation method contribute to the greenhouse gases and via greenhouse effect have an impact on everybody's lives on Earth. Hopefully by reading this thesis people will have a more environment-friendly way of thinking.

The following chapters will explain what greenhouse gases are and how do they effect nature and humans. There will also be a closer look at the emissions that are created even before the fuel tanks are filled and the plane takes off. Depending on the amount of information that is available, there are a few methods of how to calculate carbon dioxide emissions that are created due to aviation. In chapter six there is a more detailed explanation of those methods and when each of them should be used. Still, calculating the exact number of CO_2 released in the atmosphere is next to impossible. In chapter seven there is a look at the estimated CO_2 emissions in the year 2009 along with an example calculation of the amount of emissions of an individual flight route.

2 BACKGROUND AND PURPOSE

Globally, China is a major civil aviation power and its rate of development of civil aviation industry has now reached an unexpectedly high level. On one hand, the civil aviation transportation's safety and speed features have brought great ease to people's lives and the transportation also plays an important role in the development of the national economy.

However, the number of aircrafts increasing year by year as well as national routes and the frequency of the number of flights, coupled with the use of large aircrafts in recent years, has now lead to a rapid increase of fuel consumption. Therefore the civil aviation industry has produced atmospheric pollutants and greenhouse gas emissions. In recent years, the aircraft take off and landing emissions coupled with pollutants discharged by motor vehicles have affected the living environment resulting to a certain degree of damage. In addition, taken into consideration that planes flying at high altitudes emit atmospheric pollutants that are more effective compared to emissions emitted on ground level, pollution from aircrafts in high altitude are also worth attention and research. (Yan & Wu 2013.)

Since China is in the primary stage of socialism, with its unique model of economic development, the extent of the development and geographical distribution is also very closely linked to the civil aviation industry. Chinese civil aviation airport-concentration depends on the size of the cities. Therefore research on aviation emissions should be done primarily in the areas where there are many airports in a relatively small area. The east of China is more developed economically, with bigger cities and more airports thus justifying the advanced research on aviation emissions in that part of the country. (Yan & Wu 2013.)

The overall development of civil aviation is an upward trend hence pollution emissions are also increasing. As new aircrafts are added to the fleet, civil aviation science and technology are also updated because new aircrafts use more up to date mechanics. Advanced aircraft engine combustion efficiency and other technological innovations have led to great reducing of the emission factor. With the green theme in people's minds and the love for the environment, reducing emissions has become a very important concern. (Yan & Wu 2013.)

Great efforts to develop civil aviation and to ensure the harmonious coexistence with the environment are challenges placed in front of the civil aviation employees as well as all citizens. The civil aviation industry pollution emissions data, statistics and analysis developed for the General Administration of Civil Aviation of China will be studied in this thesis as well as the feasible and effective methods and measurements of carbon dioxide emissions. (Yan & Wu 2013.)

In order to reduce pollution emissions and operating costs, aviation technology and aviation fuel combustion efficiency need to be improved by an in-depth research. This leads to the development of a highly efficient and environmentally friendly air traffic. On the other hand, to raise the awareness of environmental protection and optimize the civil aviation personnel allocation, the improvement of the civil aviation management and creation of more sophisticated means of operations are necessary, thus enhancing the civil aviation resources and efficiency to complement the growing economical development. (Yan & Wu 2013.)

2.1 Impact of global warming on nature and humans

Global warming and the climate change it causes has become a global environmental problem. The world's leaders and people are paying more and more attention on this topic. Human health depends on a good environment. Direct impact on human health effects of extreme heat is generated. The impact will become more frequent and widespread. Research data shows that on the day of abnormal temperatures, the mortality rate will increase 1-2 times. Another way how climate change may affect human health is to increase the spread and range of disease-causing air-born viruses and bacteria as the Earth warms up. (Geocraft 2011 ; Keatinge 2004.)

2.2 Climate change: global warming

The increase of greenhouse gases will reduce the concentration of infrared radiation in space radiation and change Earth's climate. The need to learn how to release the right amount of greenhouse gases is therefore needed to restore the correct radiation balance. This transformation may consist of warming of Earth's surface and the lower part of Earth’s atmosphere, because it can be surplus of outgoing radiation. Nevertheless, the spread of Earth's surface temperature increases may trigger other changes, such as cloud amount in the atmosphere and changes in circulation. Some changes partly intensify or partly restrain the warming of the ground temperature. (IPCC 2001; Mukheibir & Ziervogel 2006.)

According to the complicated pattern of climate, ‘The Climate Change Special Committee’ states in their global assessment report number three, that the average temperature will increase by 1,4 to 5,8 degrees in the next hundred years. This temperature change is expected to lead to variations of the amount of suspended particles in the atmosphere creating a cooling effect and variations in the oceans’ capacity to absorb heat, which is extremely important. However, there are a lot of factors that might not be affected, such as greenhouse gas emissions and future climate changes. (IPCC 2001; Mukheibir & Ziervogel 2006.)

2.3 The rise of sea-level

As global warming is occurring, there are two processes which lead to the rising of the sea-level. The first is the expansion of water molecules due to the rise of temperature. The second is the melting of ice on Greenland and Antarctica that will also contribute to an increased amount of ocean water. The average expected sea level rise from 1900 to 2100 is assumed to be 0,09 to 0,88 meters. (Titus, Greene, Brown, Yohe 1991.)

2.4 Economy

More than half of the population in China who are living within 100 km of the coast are living in urban areas by the harbor. Therefore, the notable rise in sea level in coastal areas and low-lying islands will cause serious economic harm, such as seawater levels rising to such an extent that it occupies the beach and even parts of the inland areas therefore driving the population to move further inland. This will present many problems especially in the areas that are already tensely populated. (Thilk 2007.)

2.5 Agriculture

When the concentration of CO_2 is high, plants will grow more rapidly and taller. However, the result of global warming may affect the atmospheric circulation, and thus the global precipitation pattern as well as the soil moisture contents over various continents might change agriculture in a very harmful way. Sudden negative changes in farming and food production might lead to famine. (IPCC 2001.)

2.6 Ecology

The disappearance of coastal areas will certainly decrease the amount of fish; especially the number of shellfish. Estuaries could also reduce the abundance of freshwater species of the area and instead increase the habitation of marine species within it. As for the impact of the overall marine ecosystem, the effect of the disappearing march areas is not yet known. (IPCC 2001.)

2.7 Water cycle

Global precipitation is likely to increase. At the same time the change in regional rainfall remains still unknown. Some parts may experience increased rainfall whilst others might experience reduced amount of rain. In addition, the temperature increases will increase the moisture evaporating from the ground making the greenhouse effect stronger. (IPCC 2001.)

3 GREENHOUSE GASES

Many chemical compounds found in the Earth's atmosphere act as greenhouse gases. These gases allow sunlight to enter the atmosphere freely. When sunlight strikes the Earth's surface, some of it is reflected back towards space as infrared radiation (heat). Greenhouse gases absorb this infrared radiation and trap the heat in the atmosphere. Over time, the amount of energy sent from the sun to the Earth's surface should be about the same as the amount of energy radiated back into space, leaving the temperature of the Earth's surface roughly constant. Many gases exhibit these greenhouse properties. Some of them occur in nature (water vapor, carbon dioxide, methane, and nitrous oxide), while others are exclusively human-made (like gases used for aerosols). Table 1 illustrates the main greenhouse gases' characteristics. In Table 1 shows how carbon dioxide, methane, nitrogen monoxide, chlorine fluorine carbon compound and sulfur dioxide are produced, where they react and their effect on the environment. (NEIC 2003.)

Greenhouse gases	From	Reaction	Environmental effect
Carbon dioxide (CO_2)	1) Fuel 2) Change of land use（Deforestation）	1) Absorbed by the ocean 2) Photosynthesis in plants	Absorb infrared radiation, affecting the concentration of O_3 in the stratosphere.
Methane (CH_4)	1) The burning of the organism 2) Intestinal fermentation	1) With OH has the chemical reaction. 2) In microorganism absorption by soil	The absorption infrared emission, affects in the troposphere O3 and OH density, affects in the stratosphere O3 and H2O density, produces CO2
Nitrogen monoxide (N_2O)	1) The burning of the organism 2) Fuel 3) Chemical fertilizer	1) Absorbed by soil 2) Decomposed by the ray in the isothermal layer of the atmosphere	Absorption infrared emission, affects the density of O_3 in isothermal layer of the atmosphere.
Chlorine fluorine carbon compound (CFC_S)	Industrial production	Chlorine fluorine carbon compound is not decomposed in the troposphere easily, but it will decompose in the stratosphere and has chemical action with the O production by ray.	Absorption infrared emission, affects the density of O3 in isothermal layer of the atmosphere.
Sulfur dioxide (SO_2)	The combustion of coal and organism	With OH has chemical reaction.	Forms the suspended particle to scatter the solar radiation.

Table 1. Several main greenhouse gases’ characteristics. (adapted from NEIC 2003.)

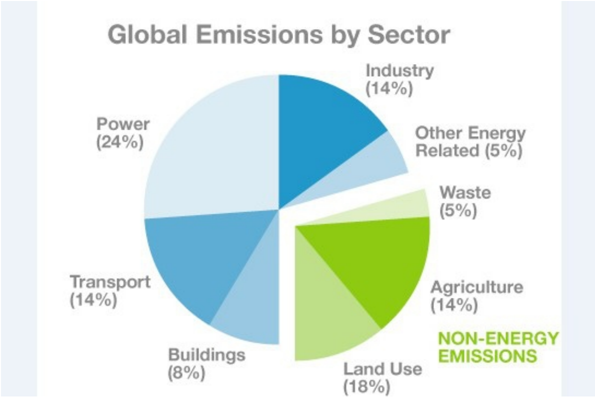
4 EFFECT OF CARBON DIOXIDE EMISSIONS

Carbon dioxide takes a portion of 72,37% among all greenhouse gases. The amount of carbon dioxide has remained nearly constant for decades as a result of increasing levels of CO_2 being followed by an increasing absorption of the emissions. About 80% of carbon dioxide in the Earth's atmosphere derives from breathing process of animals and humans. The remaining 20% comes from the burning of fuel. Carbon dioxide is soluble in water. Over 75% of carbon dioxide in Earth's atmosphere is absorbed in oceans, lakes, streams and rainfall. Furthermore, 5% of carbon dioxide is stored in organic form through photosynthesis. This is why the percentage of carbon dioxide in air remains 0.03%. (Broecker1996.)

In the last hundred years or so, a large amount of carbon dioxide has been created as results of population blooming and industrial development. Natural gases and burning of petroleum products are the direct reasons. Simultaneously, human activities such as over-lumbering, industrial area expansion and vegetation losses break the carbon dioxide balance. Additionally, the decreasing of surface water and precipitation leads to the decline of carbon dioxide solubility. Because of this, the balance is broken and the amount of carbon dioxide increases year by year. Increasing carbon dioxide percentage causes the Earth's surface temperature to rise. (Broecker 1996.)

4.1 Global Emissions

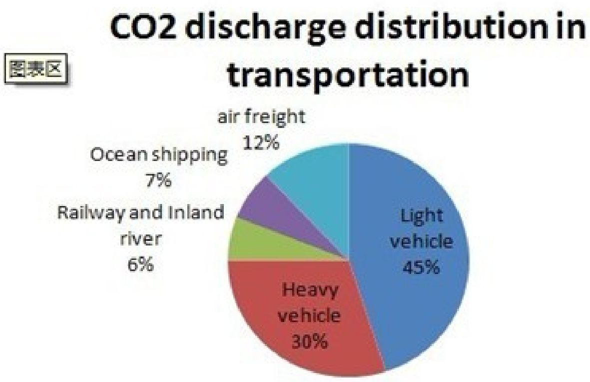
According to 'The United Nations Intergovernmental Panel on Climate Change' 's (IPCC) report by Sir Nicholas Stern published in October 2006 the largest contributor to human-induced CO_2 is power generation (24%), mostly produced in coal and gas fired stations. Next is land use change at 18%, then agriculture, industry and transport at 14% each (aviation is part of transport). The rest consists of buildings (8%), other energy related activities (5%) and waste (3%) as illustrated in Graph 2. (Eggleston 2006.)



GRAPH2. Global Emissions by Sector (Enviro. Aero 2006.)

The influence of air transportation is easily underestimated. A research from United Nations shows that merchant shipping carbon dioxide emission is thrice bigger than estimated. Based on the report of English newspaper the Guardian, discharge value of carbon dioxide is 1,12 billion per year. It is about 4,5% of total carbon dioxide emission. International maritime organization had predicted 0,4 billion before. (Cleanteach 2008.)

The percentage of carbon dioxide emission in different departments is illustrated in Graph 3 below. According to Graph 3 the CO_2 discharge distribution in transportation consists of 12% of air freight, ocean shipping 7%, railway and inland river 6%, heavy vehicle 30% and light vehicle 45%.



GRAPH3. CO_2 discharge distribution in transportation. (Enviro. Aero 2006.)

So far, air transportation industry will continue its fast development. However, the pollution discharge value will also increase at the same time. This is why it is important to analyse and calculate air transportation carbon dioxide emission, and study the influence of emission to environment. Based on the influence, necessary measures could be taken to achieve control of both air transportation developing and pollution.

5 THE SOURCE OF CIVIL AVIATION FUEL AND ITS POLLUTION

At present, the world's airlines' usage of aviation fuel can be divided into two major categories: Avgas and jet fuel. They are used in different types of aircraft engines. Avgas is used as a piston aero-engine fuel. The quality requirements for Avgas and gasoline used in automobiles are similar. Jet fuel is used in jet engines. Nowadays big aircrafts mainly use jet engines and therefore jet fuel, so the usage of Avgas has been significantly reduced. The most widespread jet fuel is kerosene, often called aviation kerosene. (Aviation Justice 2011.)

5.1 Types of civil aviation fuel

Aviation fuel is a specialized type of petroleum-based fuel used to power aircrafts. It is generally of a higher quality than fuels used in less critical applications, such as heating or road transport. It also often contains additives to reduce the risk of icing or explosion due to high temperatures, among other properties. (Static-shell 2007.)

5.1.1 Avgas

Avgas can only be used in aircrafts powered by piston engine. Avgas has a lower volatility than motor gasoline. The high octane value of Avgas comes from the addition of tetraethyl lead, which is strongly toxic. It is 100 times more toxic than lead. A human can be poisoned by a touch of skin or breathing. When it gets into human body, it will partly be transferred into a compound which can attack human's central nervous system. Avgas is divided into different classes by the content of lead. The most common one is Avgas 100LL which contains two grams of lead in one gallon. In short, Avgas is a kind of gasoline containing lead and has high octane value. (Bas 2011; Api 2013.)

5.1.2 Jet fuel

Jet fuel is used only in aircrafts powered by jet engine that have turbine engines. Jet fuel is more stable than gasoline. Gasoline is easy to volatilize, easy to burn. Diesel has a high viscosity; it is not suitable for turbine engines because fuels will be shot by very fine nozzles. Jet fuel is a better choice compared to gasoline and diesel; it has a suitable density, high calorific value, fine combustibility. It can face the demand of flying over cold areas and also the requirement of fuel flow ability. Jet fuel needs additives for its performance. TEL (Tetra-ethyl lead) is used for improving jet fuel's flash point. Antistatic agents reduce static to prevent sparkles. Corrosion inhibitors are added into jet fuel to prevent corrosion. (Api 2000; NSGNestwork 2013.)

5.2 Refining of jet fuel

The refining of jet fuel is divided into several stages. First, the base of fuel is refined from the distillation processes where the fuel is separated from crude oil. However, if only separated from crude oil, the fuel will not meet the demand of quality. Upgrading processes are widely used in producing of jet fuel, such as sweeting, hydrotreating and clay treatment. The last part is conversion processes. At this step the molecular structure is cracked. At minimum jet fuel needs to meet the demands of crystallization point (freezing point) and flashing point. (Trencome 2007.)

5.3 Refining of Avgas

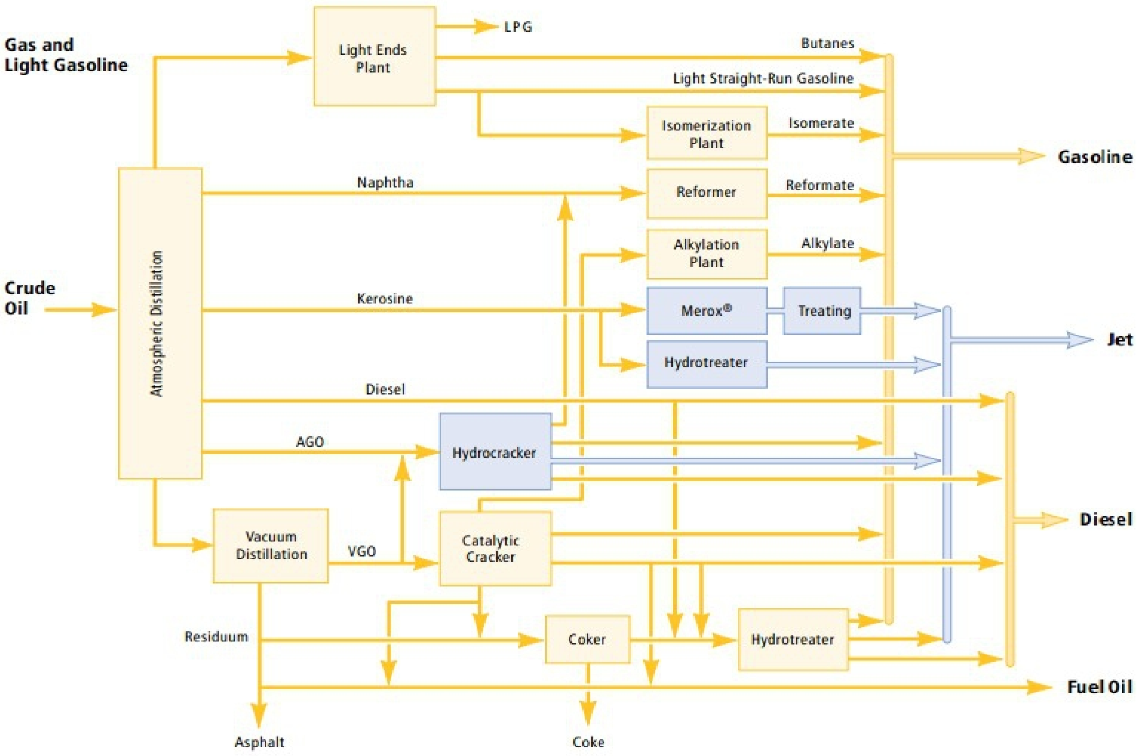
Avgas is also created by distillation of crude oil. However, the straight-run distillates cannot meet the performance demand of Avgas, because it needs higher octane value. All straight-run gasoline distillates have low octane values from 50 to 70. Along with the high performance aircraft engines being developed, higher octane value Avgas is needed. Nowadays, two refining processes from 1930s still play a major role in Avgas refining. The alkylation process and catalytic cracking were both strongly generalized by World War 2.

During the war better engines were developed which required better performance fuel. The alkylation process gives higher molecular weight and higher boiling isoparaffins by making isobutylene react with isobutane in the presence of a strong acid. (Greg, Boval, Bacha, Barnes, Franklin, Gibbs, Hogue, Lesnini, Lind & Morris 2004.)

FCC (fluidized-bed catalytic cracking) is the most widely used secondary operation in the refining process. 80% of the gasoline produced in China is produced via FCC. FCC is a process using relatively heavy distillate from crude oil to produce dry gas, gasoline, diesel and LPG. The feed is raised and gasified into risers mixed with high temperature (up to 700℃） catalyst. After the reaction, the oil gas produced in the reaction and catalyst are separated by cyclone separator in settler. The catalyst goes to the regenerator through regeneration inclined pipe. The regenerator burns down the coke attached to the catalyst to regenerate its activity. The separated gas oil goes to the fractional column to be roughly separated into rich gas, crude gasoline, crude diesel, recycle oil and slurry oil. Then the absorption-stabilization system separates the crude gasoline and rich gas into dry gas, LPG and gasoline. (Greg, Boval, Bacha, Barnes, Franklin, Gibbs, Hogue, Lesnini, Lind & Morris 2004.)

The FCC process cannot directly produce Avgas that meets the performance demand; it needs to be blended with high octane component. Normally, Avgas is blended with two or more components to achieve the desired properties, because the aircraft engines' requirements are hard to meet even for light alkylate. (Greg, Boval, Bacha, Barnes, Franklin, Gibbs, Hogue, Lesnini, Lind & Morris 2004.)

5.4 Typical process of jet fuel refining



GRAPH 4 Typical process of jet fuel refining. (DieselNet 2013a.)

Graph 4 shows a typical process of jet fuel's refining. The process is designed and optimized for overall performance, which is feasible in an economic way. Nowadays, there are hundreds of processes that can be chosen from. The determinants are the raw material that is available and what product is wanted to produce. The process seen in Graph 4 is a fuel scheme; there are LPG, gasoline, jet fuel, diesel, fuel oil and asphalt. From the graph can be seen that crude oil is the raw material. The final products of this process can also be the raw materials of some other processes. (Majewski & Jääskeläinen 1998.)

Graph 4 also shows, that gas, light gasoline, naphtha, kerosene, diesel, AGO and distillates from the bottom of the tower first distillate out from atmospheric distillation process which cannot lead to a final product. In the refining industry, this is called one processing device. Then gas and light gasoline go to Light Ends Plant as raw materials to produce LPG as a final product. The rest of the Light Straight-Run Gasoline is also a final product which is about to be blended with other components. The Reformer unit gets naphtha from distillation column to give blending components to gasoline. Gasoline is blended by many blending components from different units using different processes. Diesel components are made from atmospheric distillation, hydrotreater, catalytic cracker, and hydrocracker. (Majewski & Jääskeläinen 1998.)

Jet fuel is also a product blended to meet the performance demand. These components come from a patent refining process called Merox where kerosine is the raw material to produce jet fuel before it goes to Treating unit and Hydrotreater unit which also take kerosine as raw material. Hydrocrackers take AGO and coker as feed, which also are donative blending components of jet fuel. The whole process of choosing a technology of processing is actually a process of optimization and compromise. (Majewski & Jääskeläinen 1998.)

5.5 The pollution and emission of refining of civil aviation fuel

People assume that the aviation pollution and emission take place up in the sky, which is rather questionable if we pay more attention to emission that takes place on the ground . The demand of required civil aviation and choosing an airplane as the means to travel have already built the foundation to increase emission and pollution. The demand and decision themselves require to drill more crude oil and build new refining plants. Not to mention that people need to get to the airport and back somehow, usually by car. (Gerdes & Skone 2009.)

5.6 Crude oil extraction

When oil is being drilled, the well needed to get oil up to the ground. In some extreme conditions, the oil well can be 6000 meters deep. When the pressure difference is not big enough to push crude oil up out of the well, water needs to be injected down to the well.

Nowadays, a more efficient technology has been invented, which is polymer oil-displacing agent. One of the active ingredients of polymer oil-displacing agent is PAM (polyacrylamide). A great amount of this kind of water soluble polymer is injected into ground, but the effects of this technology are not yet defined. (Gerdes & Skone 2009.)

Oil pipes or oil wells might be located under the sea. It is possible that they have leaks. This is very harmful not only to human environment and society but maybe even more so to sea animals and sea environment. Some accidents that happen under water pollute great sea areas may need hundreds of years to recover. (Daily Express 2011.)

5.7 Civil aviation fuel

Besides drilling the earth, fuel is burnt as well. After drilling crude oil out from the ground, further pollution and emission are produced in the refining process. There are many pollution and emission sources in a refining plant. Firstly, the refining plant itself is a fuel requiring source. There are many furnaces and boilers in refineries heating up the raw material or other functions. The main emission releaser on Earth is combustion; most of the emissions come from it. Greenhouse gases are the biological descendants of combustion. Because almost all products cannot face the demand of the market, they are made use in sweetening, sulfur removal and purification processes. These processes all extract significant amounts of sulfides like hydrogen sulfide (which is highly toxic), nitride and large amounts of carbon dioxide. These emissions may not only cause greenhouse effect, they may also strongly threaten humans' health. They may cause cancer, heart disease and other diseases. (CAA 2011.)

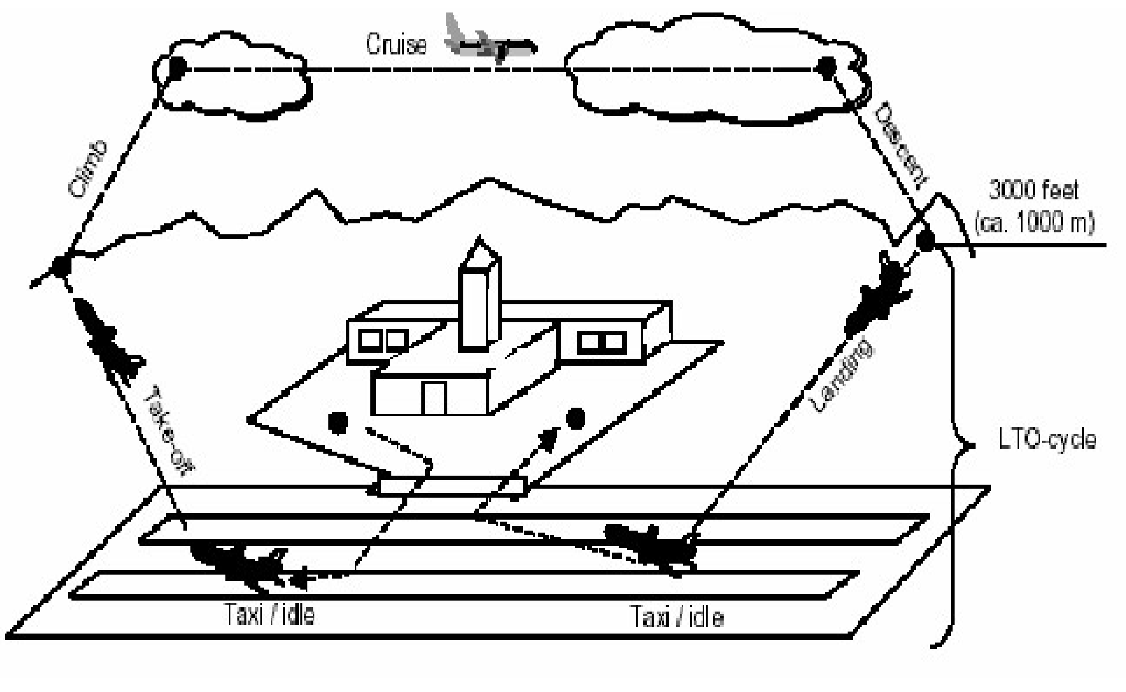
Other pollution and emission sources are easy and clear to notice and find. Others are not, like refining of fuel. The most evident source of emission occurs when the aircrafts take off but the pollution occurring while producing fuels should not be forgotten. Most of the polluting has already occurred before the fuel goes to the market. The solution would not be a single action, it will be a series of actions, including reducing the demand of take-offs, providing more efficiency and clean travelling solutions, enhancing the engine's performance in fuel consumption and many other combinations. That is not a problem only for the progress of technology but also for the administration of public transportation. More scientific administrative laws and regulations are very helpful for reducing pollution and emission. Any unitary or simple solution will not cure everything at once; there has to be combination of solutions. (CAA 2011; Gerdes & Skone 2009.)

6 CALCULATION METHODS

There are three different kinds of methods to calculate CO_2 discharge. The accuracies of these calculations are different. The method that is best suitable depends on which information is available and different influential factors such as, flight distance, air plane type, fuel type, fuel consumption and average discharge coefficient.

6.1 Flight phase classification

A voyage of an airplane is divided into six parts as seen in Graph 5. First, airplane taxis or idles on the airstrip. Second, airplane takes off until the height achieves around 1000m. Third, airplane starts to climb. Fourth, airplane cruises on the appropriate altitude. Fifth, airplane starts to descend at the end of the voyage. Sixth, airplane starts to land on the airstrip below the altitude of 1000m. The processes below altitude 1000m belong to the LTO-cycle. The completed processes are illustrated in the graph below. (Francisco 2012.)



GRAPH 5. Phases of flight of aircraft (Jardine 2005.)

6.2 Calculation method

The sources of CO2 emission in air transportation are combustions of kerosene and aeronautical gasoline. The influential factors of CO_2 emission include the type of air plane, the model of engine, fuel type, fuel discharge coefficient, flight distance and airplane operating condition, as listed in Table 2. There are three calculation methods that are suitable for CO_2 discharge.

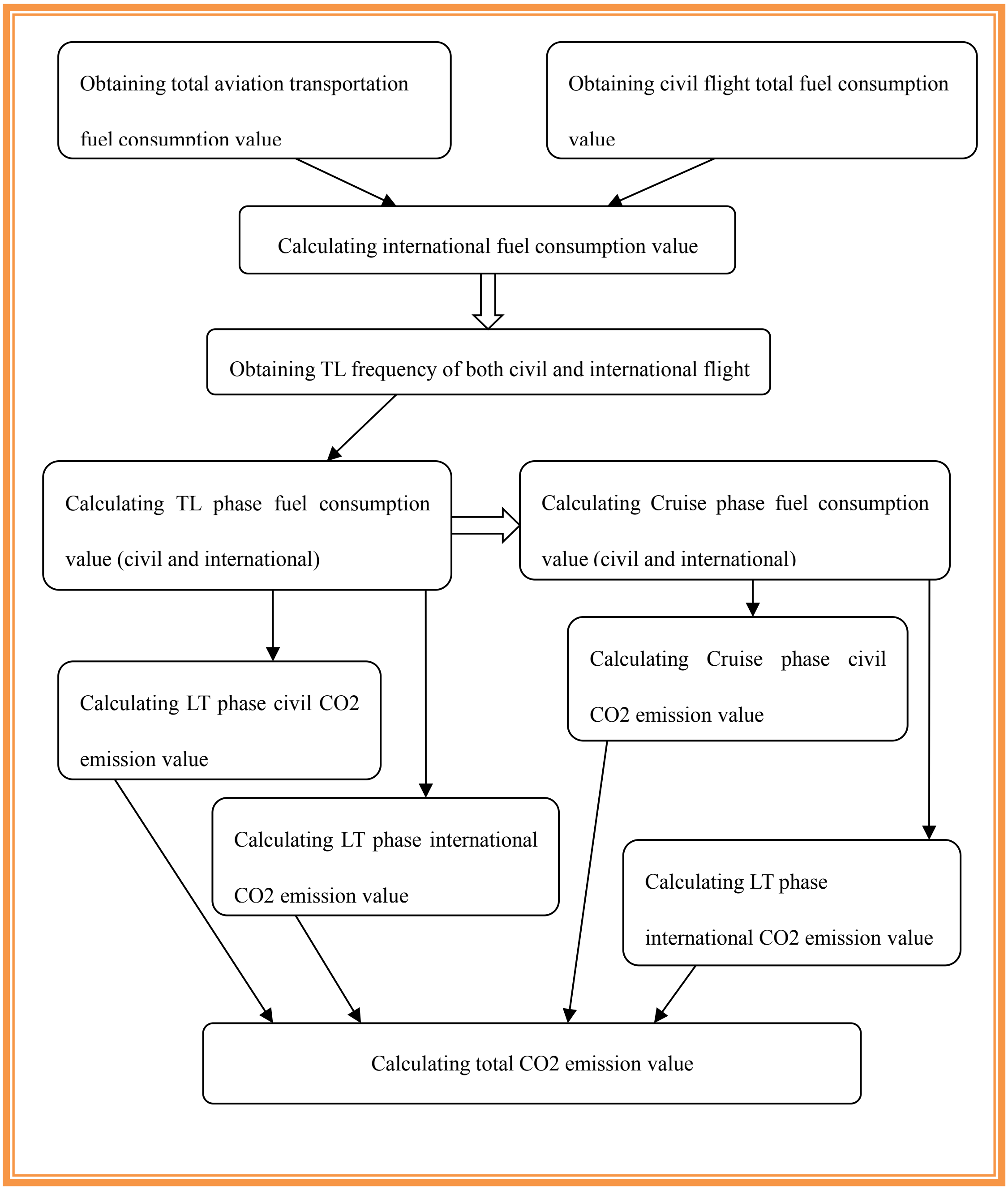
1. Airplane Type
2. Engine Model
3. Fuel Type
4. Fuel Discharge Coefficient
5. Flight Distance
6. Airplane Operating Condition

TABLE 2. Influential factors of CO_2 emissions

In the first method, the basic data collection is the total fuel consumption of civil aviation. The detail process is simple. The first step is obtaining the total fuel consumption. The second step is calculating CO_2 emission. The source of CO_2 discharge is fuel combustion where the percentage of aeronautical gasoline is low. Mainly, the fuel in calculation is kerosene. The Fuel Discharge Coefficient is the main point of CO_2 emission calculation. The formula of calculating CO_2 discharge value is total CO_2 emission value is equal to fuel consumption times Average discharge coefficient. (Jardine 2005.)

The second method is also simple. First, the flight voyage is divided into two processes, TL (take-off and landing) process and cruise process. The CO_2 discharge values of two processes are calculated respectively. Adding the two values together, the total CO_2 discharge value is obtained. In the case of Chinese civil aviation, international flight and civil flight are different because of the disparity in the cruise process. The percentages of cruise process among all processes are different. (Rypdal 1996.)

The calculation process of total CO_2 emission value is illustrated in Graph 6. There is shown how the information of total CO_2 emission value is achieved by first obtaining total aviation transportation fuel consumption value and civil flight total fuel consumption value. Now international fuel consumption value can be calculated. Next TL frequency of both civil and international flight need to be obtained. After this both TL phase and Cruise phase fuel consumption values (civil and international) are calculated. From TL phase fuel consumption value LT phase (civil and international) CO_2 emission values can be calculated. From Cruise phase fuel consumption value Cruise phase (civil and international) CO_2 emission values can be calculated. When these four CO_2 emission values are added together, the result is total CO_2 emission value. (Kollmuss 2008)



GRAPH 6. Calculation process by graph

TABLE 3. Civil/ International flight calculation information

A	Total CO_2 emission value
B	Take and landing phase CO_2 emission value
C	Cruise phase CO_2 emission value
D	TL phase fuel consumption value
E	TL frequency
F	TL phase emission coefficient
G	Average TL phase fuel consumption value
H	Cruise phase fuel consumption value
I	Cruise phase CO_2 emission coefficient
J	Total fuel consumption value

Each calculation is Civil / international flight TL process fuel consumption (D) is TL frequency (E) times TL phase fuel consumption value (G). Civil / international flight cruise process fuel consumption value (H) is equal to total fuel consumption value (J) minus TL phase fuel consumption value (D). Civil / international flight TL phase CO_2 emission value (B) is TL frequency (E) times TL phase emission coefficient (F). Civil / international flight cruise phase CO_2 emission value (C) is equal to Cruise phase fuel consumption value (H) times cruise phase CO_2 emission coefficient (I). Civil / international flight total CO_2 emission value (A) is equal to TL phase CO_2 emission value phase (B) plus cruise phase CO_2 emission value (C). From table 3 it is seen that D=E*G, H=J-D, B=E*F, C=H*I, A=B+C. (Yan & Wu 2013)

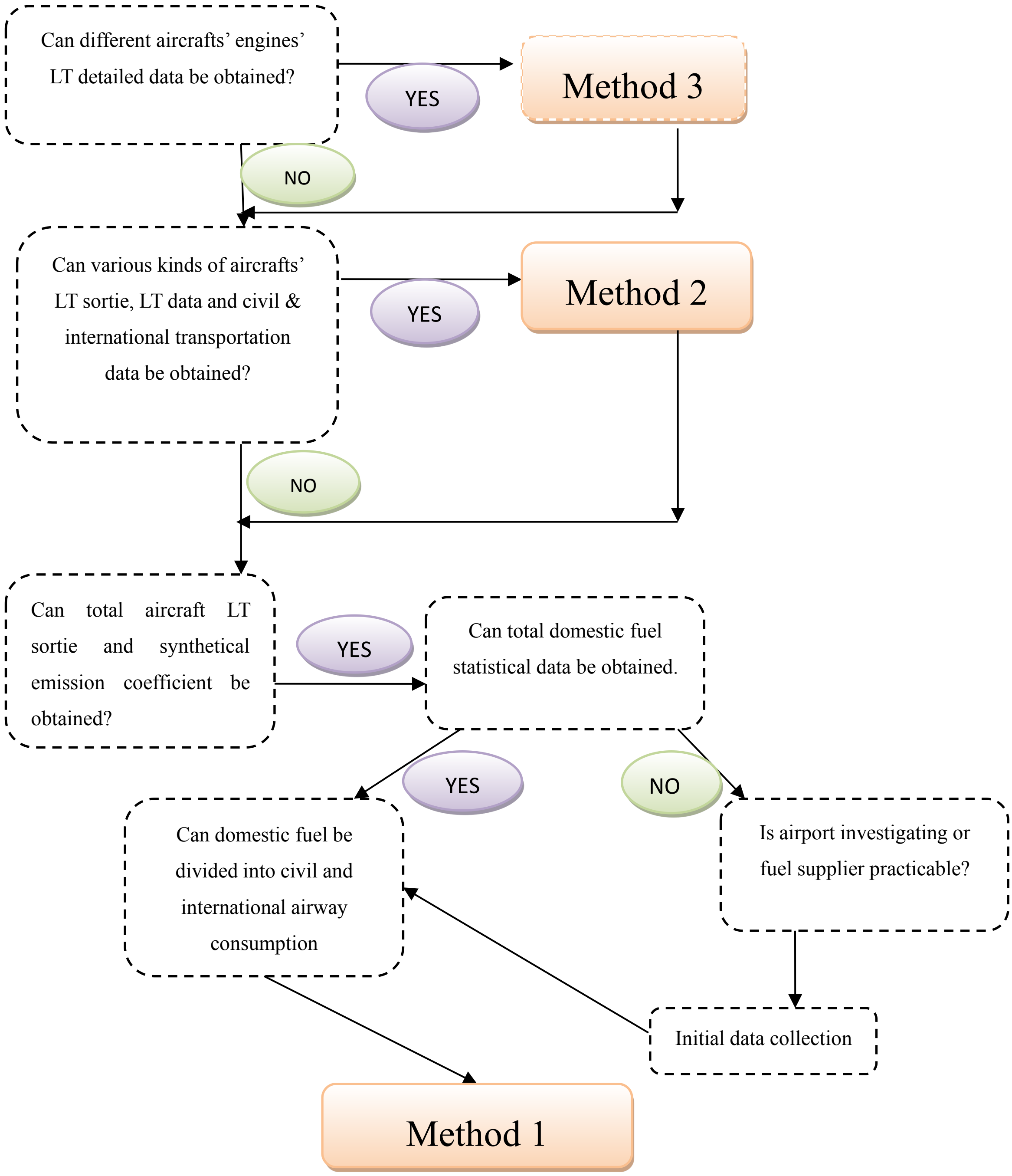
The third method is the accuracy calculating method. Here, the CO_2 emission value calculation is based on achieved flight data. According to diverse aircrafts, the fuel consumptions per unit distance are also different. In this method, both flight distances and aircraft types are different. Therefore the fuel consumption needs to be calculated respectively. (Yan & Wu 2013)

The detail steps include obtaining aircraft type and flight data, voyage distance, various kinds of aircrafts' fuel consumption along with distance from database and calculating CO2 emission value. The data is achieved from civil aviation records, airport records and air traffic control agencies or air freight guide schedule. The formula is CO2 emission value equal to Fuel consumption times Emission coefficient. (Yan & Wu 2013.)

6.3 Selection of method

In the previous chapter, there were three different methods introduced. The accuracies of these calculations are different. Therefore, the data needed for the calculation is also different. The method selection is made from analysis illustrated in Graph 7.

If the detailed data of different aircrafts' engines' take off and landing phase CO_2 emission value can be obtained, the third method can be used. If not, the information from various kinds of aircrafts' take off and landing's sortie should be considered, if both take off and landing's data and civil and international transportation data can be obtained. If all this information can be obtained, then method 2 can be chosen. If a part of this information is not available, the information of total aircraft take off and landing's sortie and synthetical emission coefficient need to be collected. When the total domestic fuel statistical data is also available and whether domestic fuel can be divided into civil and international airway consumption, then method 1 is suitable. Sometimes the details of total domestic fuel statistical data can not be obtained, then should airport or fuel supplier and initial data collection be investigated. (Yan & Wu 2013.)



GRAPH 7. Method Selection

7 THE CO_2 EMISSION ESTIMATION IN 2009

As explained in chapter 4 carbon dioxide is the main greenhouse gas. Reducing carbon dioxide emissions has become a common global goal. Global warming will lead to a series of disastrous consequences that can be felt all over the world. A large portion of carbon dioxide pollution of the world is produced in China. Therefore, more attention should be paid to the annual carbon dioxide emissions. This way, excessive emissions of carbon dioxide can be controlled.

7.1 Explanation of detail and method

At present, all the Chinese airway data can be obtained on the official website. According to graph 7, the usage of method 3 should be chosen because this method is the most accurate one. The CO_2 emission produced by the flights are affected by many factors, including travel distance, weather conditions (downwind/headwind), the cargo capacity, passenger capacity, and the flight altitude. The effort of calculation for CO_2 emission will be tremendous if all the above factors are considered, whilst a part of the other information affecting the CO_2 emission amount still remains hard to obtain. Therefore in a single flight distance is the main factor in calculating CO_2 emission. (Yan & Wu 2013.)

During a flight, it's not only the correlation between travel distance and fuel consumption that are the main factors for the amount of CO_2 emission produced, as it is in road transportation. In order to enable the airplane to reach the flight altitude, extra fuel will be needed. The long distance travel will also require the airplanes to carry a significant amount of fuel. (Yan & Wu 2013.)

The flight is divided into two phases. First is TL (take-off & landing) phase. The TL phase is the phase below the altitude of 1000m. In this phase, the distance is not taken into consideration because most fuel consumption in this phase is used for taking off and landing. The fuel consumption per unit time is higher than cruise phase. The second phase is cruise phase. There, all the fuel consumption happens above 1000m. The relationship between flight distance and fuel consumption is directly proportion. (Yan & Wu 2013.)

These two phases, the TL phase and cruise phase, have different percentages in various distances. In long-distance flight, cruise phase has higher percentage. In short-distance, TL phase has higher percentage when calculating CO_2 emissions. By 2008, Chinese civil aviation started 1336 regular flight routes, in which 1068 routes are civil air routes. The routes are open to 140 domestic cities. 15 Chinese air transport companies have also opened 268 international routes which go through 91 cities in 42 nations. (Chinawuliu 2007.)

Due to the vastness of variety in flight routes calculating the CO_2 emissions of each of them would be a big effort. The solution to this is classifying routes based on flight distance. Choosing the most representative airplane type for calculation will not affect the accuracy greatly and is therefore reduced from the calculation.

The classification method is based on the situation of Chinese civil air routes. The routes are now divided into two categories: feeder air route and trunk air route. Feeder air routes connect small cities with short distance. The airplanes in feeder air routes are turboprop airplanes with no more than 50 or 70 seats. Generally, the flight distance between the departure location and destination is shorter than 800km. The air routes with the distance between 800km and 1500km with no more than 36 thousands passengers per year are also called feeder air route. The frequency of feeder air route should be at least 1 regular flight per week. Trunk air routes are routes between big cities. The airplanes in trunk air routes are turboprop airplane with more than 70 seats and any other airplanes with more than 50 seats. Generally, the flight distance is over 800km. In Appendix 1 shows the number of flight routes of each aviation company using different types of aircrafts. (News 2000.)

7.2 Calculation

There is an example calculation of annual fuel consumption of a single flight route in this chapter. Based on the information of Appendix 3 feeder air route airplane type ERJ has been chosen for the calculation. Relationship between ERJ airplane fuel consumption and air-range is illustrated in Table 4. The table shows, that air-range and fuel consumption are not in proportion, for example in an air-range of 231,5 km the fuel consumption is 572,56 kg and in an air-range of 463 km the fuel consumption is 879.35 kg

Air-range (km)	231,5	463	926	1389	1852	2778
Fuel consumption (kg)	572,56	879,35	1422,60	1985,52	2561	3751,37

TABLE 4. ERJ fuel consumption and air-range (Yan & Wu 2013.)

For current domestic flights and fuel consumption summary see appendices 1-3. Table 5 shows the details of feeder air route flight from Aqsu to Urumqi (875 km). There are 14 flights a week and the data of annual fuel consumption is missing, so it needs to be calculated. The calculation can be made based on the information given by Tables 4 and 5.

Departure	Destination	Flight type	Air-range	Flight Frequency per week	Annual fuel consumption
Aqsu	Urumqi	Feeder air route	875km	14	?

TABLE 5. Annual fuel consumption from Aqsu to Urumqi (Civil flight feeder air route)

The air-range is 875km which is between 463km and 926km. Fuel consumption per flight = 879,35kg+（1422,60kg-879,35kg）/（926km-463km）(875km-463km) = 1362,8kg. The flight frequency per week is 14 times. The total fuel consumption in a week is 1362,8kg multiplied by 14times is equal to 19079,2kg. In one year there are 365 days, 7 days is one week. Weeks in a year = 365/7 = 52,14285. Annual fuel consumption = 52,14285*1362,8kg*14 = 994844kg. (Yan & Wu 2013.)

It can be seen from the calculation that the annual fuel consumption from Aqsu to Urumqi is 994844kg. This means that there is a large amount of emissions just from burnt fuel alone. On top of this come the emissions from producing the fuel. All this from a single flight route. Taking into consideration all flight routes in China, there is a vast amount of carbon dioxide released into the atmosphere every year.

8 CONCLUSION

Background about the economic development and growth in China can be found in chapter 2. Due to the growth of civil aviation in recent years there also is more carbon dioxide emissions which lead to more rapid greenhouse effect. Chapter 2 lists and explains the results of greenhouse effect and global warming. The main point of chapter 3 is to introduce the most effective greenhouse gases and their effect on the environment. Carbon dioxide is the main greenhouse gas. More information about carbon dioxide and its role in the greenhouse effect can be found in chapter 4. There are two major categories of aviation fuel. These categories are explained in chapter 5 along with information about producing these fuels and the pollution caused by the production. The calculation of CO_2 discharge is difficult. There are many factors that need to be taken into the account and the information of some of the factors might not be available. Depending on the information that is available, there are three methods that can be used to calculate CO_2 discharge. Chapter 6 introduces the methods and explains when to use each one. Calculating the total carbon dioxide emissions caused by civil aviation in the whole of China is a task, that is too big for one thesis. Instead, there is a calculation of the amount of fuel burned in a single flight route annually in chapter 7.

This thesis summarizes the main points of greenhouse effect and greenhouse gases which are causing global warming on a never before seen rate. The thesis concentrates on the carbon dioxide emissions produced by civil aviation in China, but also needs to be remembered that aviation is only one source of carbon dioxide and China is just one nation among many. Different kinds of aircraft engines are introduced and explained how the pollution from aviation is not only a problem in the air, but also on the ground. A large portion of pollution is produced even before the airplane leaves the hangar and takes on passengers or luggage.

This thesis shows that CO_2 emissions resulting from air transportation represent a large proportion of the total amount of CO_2 emissions produced from human transportation and should be taken more into consideration by the public in the future. Many intelligent minds are working on the problem of pollution even right now. A lot of today's polluting is done in the name of progress or general well being of people. Some of this progress makes our lives easier, but at some point the long-term costs should be analyzed.

Ways of minimizing CO_2 emissions from air transportation are constantly being studied and the technology of aircrafts is also under constant improvement. A way to minimize the CO_2 emission could be found by conducting more studies into the possibility of using electrically charged airplanes in the future. Also considering other means of transportation instead of air transportation especially for the shorter distance travels should be done. For instance the use of railway transportation, and new upcoming means of land transportation could be more beneficial and causing less CO_2 emission. The Maglev, a magnetic levitation transportation system, is a new innovation that uses electricity instead of burning fossil fuels. Although it is expensive to build, it will eventually be cheaper because of its low maintenance costs. Due to its high travelling speed, this transportation system would be a good alternative for traveling instead of air transportation, not prolonging the time of travel, which is also an important factor highly taken into consideration when choosing the means of transportation.

The greenhouse effect and the greenhouse gases that cause it, is a serious problem and should not be taken lightly. The subject is vast, and there are so many studies made to browse through and to choose for closer research. Global warming is a difficult problem for everyone.

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Appendix

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Number of flight routes in different aviation companies

		Three Big Airline			Local Airline					Private Airline	Other Airline
Airplane Type	Total nr of flights	International	Eastern	Southern	Xiamen	Hainan	Shanghai	Sichuan	Shandong		
B737-300	**113**	**31**	**20**	**25**		**16**			**12**	**9**	
B737-300Q C/F	**24**					**6**				**7**	**11**
B737-400	**9**					**9**					
B737-500	**3**				**2**					**1**	
B737-600	**2**	**2**									
B737-700	**122**	**20**	**32**	**28**	**15**	**8**	**4**		**3**	**7**	**5**
B737-800	**270**	**52**	**9**	**44**	**26**	**57**	**27**		**17**	**34**	**4**
B737-900	**5**									**5**	
B747-200F	**3**	**3**									
B747-400M	**6**	**6**									

Appendix

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B747-400	**4**	**4**									
B747-400F	**24**	**6**		**2**		**3**					**11**
B757-200	**48**	**13**		**17**	**8**		**10**				
B757-200SF	**2**						**2**				
B767-200ER	**0**										
B767-300	**11**	**4**				**3**	**4**				
B767-300ER	**11**	**4**	**3**				**4**				
B777-200	**14**	**10**		**4**							
B777-200ER	**6**			**6**							
MD82	**0**										
MD90	**22**		**9**	**13**							
MD11	**10**						**4**				**6**
Boeing in total	***708***										
A300-600F	**4**			**1**							**3**

Do328Jet	**29**					**29**					
ERJ145	**33**		**10**	**6**		**12**		**3**			**2**
ERJ190	**14**					**10**					**4**

Domestic aviation airplane types and distributions in May 2009. (Ya 2009.)