Estimation of Philippine Domestic Air Transportation Energy Demand

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Abstract: While bottom-up estimates have been attempted in some local studies, there are not many updated and comprehensive local studies on the air transportation energy demand in the Philippines. With a bottom-up approach, the study aims to estimate air transportation energy demand from 2010 to 2019 and identify the gaps in the available local data needed for bottom-up estimation and modelling. The Philippine air transportation energy demand is estimated using secondary flight data, fuel consumption factors from secondary sources, and estimated flight distances. Estimation results were 394 to 608 KTOE for the years 2010 to 2019, with an average percent difference of 21.56% from the official energy statistics. The study recommends establishing a comprehensive flight and fleet data collection system and the development of local fuel economies to reflect the actual local conditions of aircraft operations.

Keywords: Air Transportation, Energy Demand, Bottom-up Estimate, Energy Consumption, Energy Efficiency, Fuel Efficiency

1. INTRODUCTION

One of the long-term objectives under the Roadmap of Energy Efficiency and Conservation of the Philippine Energy Plan (PEP) 2016-2030 of the Department of Energy (DOE) (2016) is to implement programs for energy efficiency of various modes of transportation, including the aviation sector. Moreover, DOE (2017) aims to enhance the energy demand management mechanisms with the private and public sectors' participation, as stated in the PEP 2017-2040. Quantifying the transportation sector's energy consumption is one of the prerequisites for formulating policies and programs against multi-sectoral issues related to energy and the environment, such as greenhouse gas emissions, energy efficiency, and depletion of natural resources.

In the Compendium of Philippine Energy Statistics and Information, DOE (2018) reports that the air transportation sector has incurred a total final energy consumption (TFEC) of 594 thousand tons of oil equivalent (KTOE) in 2016, which was 5.2% of the TFEC of the transportation sector for that year. From 1990 to 2016, the air transportation sector's share to the TFEC of the transportation sector ranged from 1.9% to 5.9%, with an average annual growth rate of 12.3%. DOE (2018) states that the TFEC of aviation mostly includes jet fuel consumption from domestic aviation aircraft for commercial, private, and agricultural purposes.

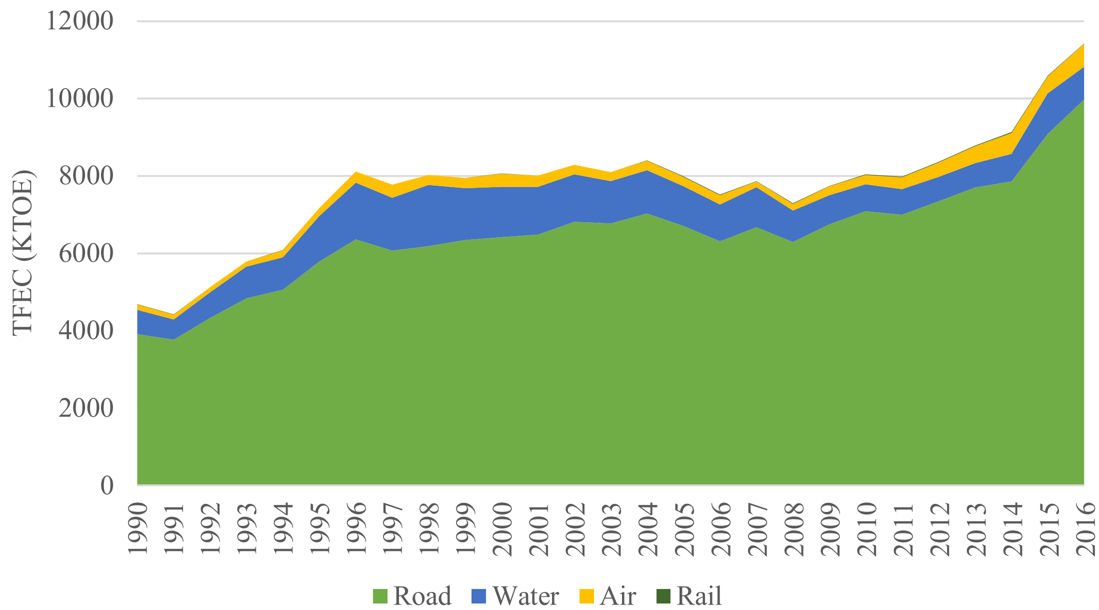

Figure 1. Total final energy consumption in transportation per mode (DOE, 2018)

The Asia-Pacific Economic Cooperation (APEC) (2019) reports that the 0.59 million tons of oil equivalent (MTOE) energy demand of air transportation in the Philippines is expected to grow to 1.9 MTOE by 2050. The report explains that the increase is due to the growth of per-capita GDP, which results in the escalation of passenger-kilometers travelled by three times. APEC (2019) based this projection on the business-as-usual (BAU) scenario, which covers existing trends, policies, and programs on energy demand and supply in the country. The study also reports the projections of energy demand using two alternative scenarios which focus on improved energy intensity and the use of more renewable energy, as well as the reduction of carbon dioxide emissions for different energy sectors, including transportation

Energy demand estimates, specifically for air transportation, performed by the DOE have been usually top-down assessments that involve fuel sales equating to the demand. These top-down models do a great job of examining the broader energy economy and the effects of price changes due to policies. However, they do not relate energy demand to actual air transportation demand, transportation activity (aircraft movements and OD data), fuel economy (or fuel efficiency), and other technological improvements in the sector.

Meanwhile, a bottom-up approach in evaluating transportation and carbon dioxide emissions was introduced by Schipper *et al.* (2009). Bottom-up models are able to better relate energy demand with current and prospective changes in transportation demand and operations. This makes bottom-up estimation more suited to analyse and evaluate changes in aircraft technology (e.g., use of fuel efficient aircraft) and effects of policies on energy efficiency and emissions standards. By combining the results of the the top-down and bottom-up analyses, more effective and comprehensive economic and technological interventions and policies may be put in place.

However, Schipper *et al.* (2009) claim that in most Asian countries and developing countries such as the Philippines, there is no sufficient data for a thorough understanding of the transportation sector using the bottom-up approach. The lack of sufficient data on vehicle fleet, transportation activity, and transportation operations establishes the difficulties in performing the bottom-up approach. While some data were obtained from reliable and published studies, the accuracy and representation of such data in local settings are still uncertain.

Gota (2014) reviewed various studies by the World Bank, Asian Development, Bank, and Clean Air Asia, which utilized a bottom-up approach to correlate the results of official top-down fuel consumption data with the results of bottom-up methodologies. Gota (2014) claims that there were discrepancies between the top-down data and the calculations in the bottom-up studies. The bottom-up estimates resulted in higher projected values than the official top-down data, which could be attributed to the correlation of vehicle growth with lower fuel consumption values. Mejia *et al.* (2017) evaluated sustainable transportation and climate change in the Philippines. They identified some problems in transportation data in the Philippines, such as uncertainty in top-down fuel sales estimates, lack of fuel economy and emission factors, inadequacy of established transportation surveys for passenger and freight, and insufficient vehicle activity data.

Bottom-up estimates have been attempted in some local studies. Despite diligent efforts, at the time of writing, there are not many updated and comprehensive local studies on the transportation sector's energy demand, especially in air transportation. With this, the study aims to estimate the energy demand of the Philippine domestic air transportation sector for the years 2010 to 2019 using a bottom-up approach. The study will attempt to apply a standard bottom-up methodology, and help identify gaps in the available local data needed for a comprehensive bottom-up estimation and modelling. The identification of gaps will hopefully encourage regular collection of those critical data. Another intent of the study is to compare the results with the official statistics to compare top-down and bottom-up estimates and offer possible reasons for those differences. Moreover, the study will also attempt to compute for the average fuel efficiency per year, from the estimated energy demand and computed transportation activity, passenger-km. Other transportation activity data such as available seat-km and passenger load factor are also derived from the estimated energy demand.

2. REVIEW OF PREVIOUS STUDIES

2.1 Philippine Air Transport Energy Demand Studies

Sigua (1986) estimated the energy demand of the four modes of transportation, namely, road, air, water, and rail, in 1980 using passenger and freight transportation demand data. For air transportation, Sigua (1986) utilized data from Philippine Airlines, which provided the most aviation services then across 83 national airports and 120 private airports. Energy demand was estimated from air transportation activity data such as the number of passengers, passenger-kilometer, available seat-kilometer, revenue-payload, freight-tons, ton-kilometers, and performance details such as block hours, kilometers flown, load factor, hours utilized per aircraft, and quantity of aircraft. Sigua (1986) estimated that in 1980, the fuel consumption for domestic routes was 96,400 TOE (tons of oil equivalent).

Bayot *et al.* (2006) updated the 1986 study of Sigua by estimating the energy demand of the four modes of the transportation sector from 1997 to 2001,. Data from government agencies and private institutions were obtained for the bottom-up assessment. Bayot *et al.* (2006) claim that the Philippines lacks comprehensive studies on the transportation sector's energy demand. An average annual fuel consumptionfrom 1997 to 2001 was assumed for air transportation, which was then proportioned to the annual number of aircraft movements in the same period. Data on the frequency of flights per week, hours flown of aircraft, and fuel rate were gathered from airline companies to estimate the fuel consumption in barrels of fuel-oil equivalent (BFOE). Bayot *et al.* (2006) assumed one representative aircraft for each airline company in their calculations. The results were proportioned with the theoretical and actual aircraft movements to obtain the actual energy consumption. Table 1 summarizes the aircraft movement and estimated energy demand of air transportation from 1997 to 2001 by Bayot *et al.* (2006).

Table 1. Aircraft movement and energy consumption of air transportation (Bayot *et al.*, 2006)

	1997	1998	1999	2000	2001
Aircraft movement	219,682	171,816	181,650	164,674	170,508
Energy consumption (BFOE)	4,788,346	3,745,024	3,959,373	3,589,352	3,716,514

Baal and Fulgencio (2019) estimated greenhouse gas emissions from the Philippines' domestic air transportation for the year 2014. The researchers conducted a survey using an online flight tracker to obtain the frequency of trips per domestic route per aircraft type. They proportioned the results to the aircraft movement count from the Civil Aviation Authority of the Philippines (CAAP) for their estimation. They also utilized the Philippine Enroute Chart in the estimation of cruising distances. Baal and Fulgencio (2019) disaggregated their calculations to LTO (landing and take-off) and CCD (climb, cruise and descent) phases of a flight. For the LTO phase, Baal and Fulgencio (2019) based their calculations on alternative methodologies while incorporating local airport details such as runway length and the number of runways per airport, among others. On the other hand, the researchers used the factors from the 2006 EMEP/EEA Air Pollutant Emission Inventory Guidebook for the CCD phase. Baal and Fulgencio (2019) report that 753.41 kilotons of jet fuel was consumed in 2014. Their calculations are limited only to domestic flights across 33 airports in the Philippines. Baal and Fulgencio (2019) computed greenhouse gas emissions using the emission factors from the 2006 EMEP/EEA Air Pollutant Emission Inventory Guidebook.

2.2 ICAO Carbon Emissions Calculator Methodology

The International Civil Aviation Organization (ICAO) (2018) developed the ICAO Carbon Emissions Calculator which estimates carbon emissions (CO_2) per passenger in a flight. The tool uses a distance-based approach and data on a variety of aircraft types to compute the emissions. ICAO (2018) developed a formula to estimate fuel consumption based on a wide range of data collected globally.

ICAO (2018) requires input variables such as city pair, great circle distance (GCD), load factors, fuel/km, and the number of Y-seats (economy seats) of a flight in their calculation tool. First, the tool searches its database for all flights and the coordinates of the airports to determine the GCD of the flight. GCD is the shortest path between two points on the surface of a sphere. Since the GCD is only an approximation of the distance flown by an aircraft, a correction factor is applied depending on the distance between the origin and destination airports. This is done to account for the distance flown in excess of the GCD, stacking, traffic, and weather-driven conditions. Table 2 shows the GCD correction factors used in the computations of ICAO

Table 2. GCD correction factors (ICAO, 2018)

GCD	Correction to GCD
Less than 550 km	+50 km
Between 550 km and 5500 km	+100 km
Above 5500 km	+125 km

Then, a passenger load factor is applied depending on the route group of a flight. Load factors are based on 53 international route groups and 11 domestic areas. After the flight information is obtained from its database, the aircraft type is mapped into one of the 312 equivalent aircraft types in the aircraft fuel consumption database developed by ICAO (2018). Next, the total fuel consumed is derived from the ICAO Fuel Consumption Formula depending on the flight distance and aircraft/equivalent aircraft type. ICAO (2018) did not show the fuel consumption formula but provided fuel consumption tables instead. The maximum number of Y-seats is obtained using a standard cabin layout from the Manual on Airplane Characteristics for Airport Planning. ICAO (2018) computes the CO_2 emission per passenger following the formula below.

$$E_{CO_2} = 3.16 * \frac{TF \ * PF \, factor}{Y * PL \, factor} \tag{1}$$

where,

E_{CO_2}	: CO_2 emission per passenger,
TF	: total fuel,
PF	: passenger-to-freight factor,
Y	: number of Y-seats, and
PL	: passenger load factor.

The passenger-to-freight factor is the ratio of the number of passengers to freight tonnage of a route group based on the ICAO statistical database. On the other hand, the passenger load factor is the ratio of passengers to the number of seats available in a route group. 3.16 is the factor applied to compute the tons of CO_2 generated from burning a ton of aviation fuel. The cabin class and the number of passengers inputted by the user are used to determine the cabin class correction factor. After applying cabin correction factors, the final CO_2 emission per passenger is obtained (ICAO, 2018).

Still, ICAO (2018) recognizes the limitations of its tool. First, the actual flown distance which could be sourced from airline companies, is more accurate than the GCD. Second, though aircraft types of the same equivalent aircraft type share similar performance characteristics, there are still significant differences between aircraft among its equivalent aircraft group, such as age and airlines specific configuration. There are different classes of service offered by airlines on their flights. But, to simplify the calculation, ICAO (2018) only considers two categories. The passenger load and passenger-to-cargo factors are based on the United States' data to ICAO. These data tend to change since they are updated annually, according to ICAO (2018).

2.3 EMEP/EEA Air Pollutant Emission Inventory Guidebook

The European Environment Agency (EEA) (2019) aims to establish the guidelines in the computation and compilation of air pollutant emissions in their Air Pollutant Emission Inventory Guidebook. Air pollutants such as CO_2, NO_x, CH_4, and particulate matter, among others, are generated mainly by the combustion of jet fuel and aviation gasoline, which are the primary fuels used by different aircraft types depending on their engine type. EEA (2019) describes that main engine types include piston and gas turbine engines. A piston engine uses piston and crank mechanisms to extract energy from the fuel combustion of aviation gasoline. In contrast, a gas turbine engine uses jet fuel to drive the aircraft to operate the turbine.

EEA (2019) establishes its criteria regardless of the air carrier's nationality to distinguish domestic flights from international flights. According to EEA (2019), if a flight departs and arrives in the same state, it is considered domestic. On the other hand, if a flight departs from one state and arrives in another, it is considered international.

For fuel use, top-down and bottom-up data can be collected and analyzed. EEA (2019) explains that top-down data might come from fuel sales from taxation authorities, airports, and fuel suppliers. Meanwhile, bottom-up data could be obtained by conducting surveys on airports and airline companies or using standard tables for fuel consumption based on aircraft movement data. EEA (2019) assumes that aviation gasoline is used for domestic flights only because it usually powers small aircraft types and helicopters.

The methodology developed by EEA (2019) is directed towards the computation of emissions while fuel consumption estimation is only a step back from emissions computations because emissions divided by the emission factor results in fuel consumption. Therefore, EEA (2019) establishes three tiers of methodologies. Tier 1 is based on total fuel sales and the total number of LTO and CCD cycles carried out assuming only one representative aircraft for all flights. The general equation that Tier 1 follows is shown below.

$$E_{pollutant} = AR_{FC} \times EF_{pollutant} \tag{2}$$

where,

$E_{pollutant}$	: annual emission of each pollutant for each of the LTO and CCD phases of domestic and international flights,
AR_{FC}	: activity rate by fuel consumption for each of the flight phases and flight types, and
$EF_{pollutant}$	: emission factor of pollutant for the corresponding flight phase and flight type.

After obtaining data on fuel sales and disaggregating the data into the fuel used in domestic and international aviation, fuel consumed in the LTO phase is computed based on a representative aircraft and its consumption factor developed by EEA (2019). Emissions are obtained by multiplying an emission factor developed by EEA (2019) to the fuel consumed. EEA (2019) describes that the fuel consumed during the CCD phase is computed by subtracting the fuel for the LTO from the total. The emission for the CCD phase is calculated by using an emission factor based on the representative aircraft.

The calculations in Tier 2 are almost the same as those of in Tier 1 but Tier 2 accounts for all the aircraft types (at least all representative aircraft types) and does not consider a representative aircraft for all flights as Tier 1 does. EEA (2019) provides accompanying spreadsheets of their report, namely, the Master Emission Calculator and the LTO Emissions Calculator, to show how an aircraft is mapped to its representative aircraft type. EEA (2019) considers Tiers 1 and 2 top-down assessments because total fuel sold is needed. Tier 2 follows the general equation shown below.

$$E_{pollutant} = \sum_{i} AR_{FC,i} \times EF_{pollutant,i} \tag{3}$$

where,

$E_{pollutant}$	: annual emission of each pollutant for each of the LTO and CCD phases of domestic and international flights,
i	: aircraft type,
AR_{FC}	: activity rate by fuel consumption for each of the flight phases and flight types, and
$EF_{pollutant}$	: emission factor of pollutant for the corresponding flight phase and flight type.

Meanwhile, EEA (2019) explains that Tier 3 is a bottom-up calculation which involves using actual flight movement data such as origin and destination (OD) data for Tier 3A and full flight trajectory information for Tier 3B. According to EEA (2019), Tier 3A computes fuel burn and emissions for the LTO phase and various CCD phase lengths based on average fuel consumption and emission data per aircraft type. After gathering data on the flight schedule to identify the aircraft type used, the aircraft is mapped into its representative aircraft. Then, the fuel consumption and emissions of a flight are computed for the LTO and CCD phases using the accompanying spreadsheets. Finally, the total fuel consumption and emissions are computed as the sum of the LTO and CCD fuel consumption and emissions.

On the other hand, EEA (2019) differentiates Tier 3B from Tier 3A by calculating fuel burn and emissions per flight segment in Tier 3B, using aircraft-and-engine-specific aerodynamic information and complex computer models. Tier 3B generates fuel burnt and emissions per aircraft type, engine type, airport, region, and other specific details such as latitude, longitude, altitude, and time.

3. METHODOLOGY

The energy demand of air transportation is estimated from secondary transportation activity data and fuel consumption factors for the landing and take-off (LTO) phase and climb-cruise-descent (CCD) stage. This methodology is mainly derived from the EMEP/EEA Air Pollutant Emission Guidebook 2019. It could be categorized as Tier 3A which is a bottom-up approach for aggregating the fuel burn from each flight of various aircraft types. The methodology covers the energy consumption of domestic flights from 2010 to 2019. Domestic flights are defined by EEA (2019) as flights which depart and arrive in the same state.

3.1 Calculation Flow

3.1.1 Air transportation energy demand

The calculations are executed using a spreadsheet software following the flowchart in Figure 2 and Equation 4.

$$E_i = \frac{7.88 \times 0.127}{1 \times 10^6} \sum_j \sum_k \left(CF_{LTO,k} \times TF_{j,k}\right) + \left(CF_{CCD,j} \times TF_{j,k}\right) \tag{4}$$

where,

i : year,
E_i : energy consumption (KTOE) of year i,
j : origin and destination (OD) pair,
k : aircraft type,
$CF_{LTO,k}$: LTO fuel consumption factor for aircraft type k (kg),
$TF_{j,k}$: trip frequency for OD pair j of aircraft type k,
$CF_{CCD,k}$: CCD fuel consumption factor for aircraft type k (kg),
7.88 : conversion factor from tons to barrels (BP, 2019),
0.127 : conversion factor from thousand barrels to KTOE (DOE, n. d.), and
1×10^6 : conversion factor from kilograms to tons and barrels to thousand barrels.

INPUT

OUTPUT

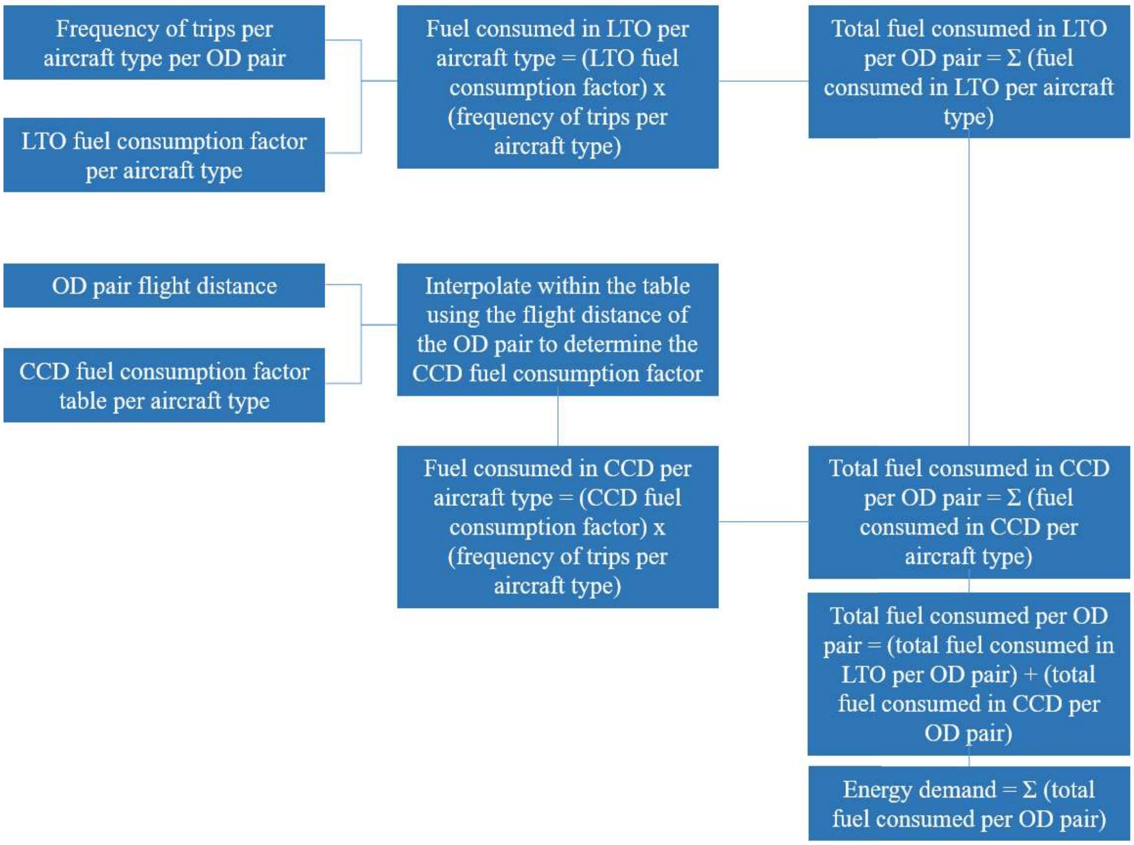

Figure 2. Flowchart for energy demand estimation

3.1.2 Passenger-km and available seat-km

The passenger-km (PKM) and available seat-km (ASKM) are calculated using Equations 5 and 6, respectively, and the flowchart in Figure 3.

$$PKM_i = \sum_j (P_j \times FD_j) \tag{5}$$

where,

i : year,
PKM_i : passenger-km of year i,
j : origin and destination (OD) pair,
P_j : passenger traffic count for OD pair j, and
FD_j : flight distance for OD pair j (km).

$$ASKM_i = \sum_j \sum_k (S_k \times FD_j \times TF_{j,k}) \tag{6}$$

where,

i : year,
$ASKM_i$: available seat-km of year i,

j	: origin and destination (OD) pair,
k	: aircraft type,
S_k	: seating capacity of aircraft type k,
FD_j	: flight distance for OD pair j (km), and
$TF_{j,k}$	: trip frequency for OD pair j of aircraft type k.

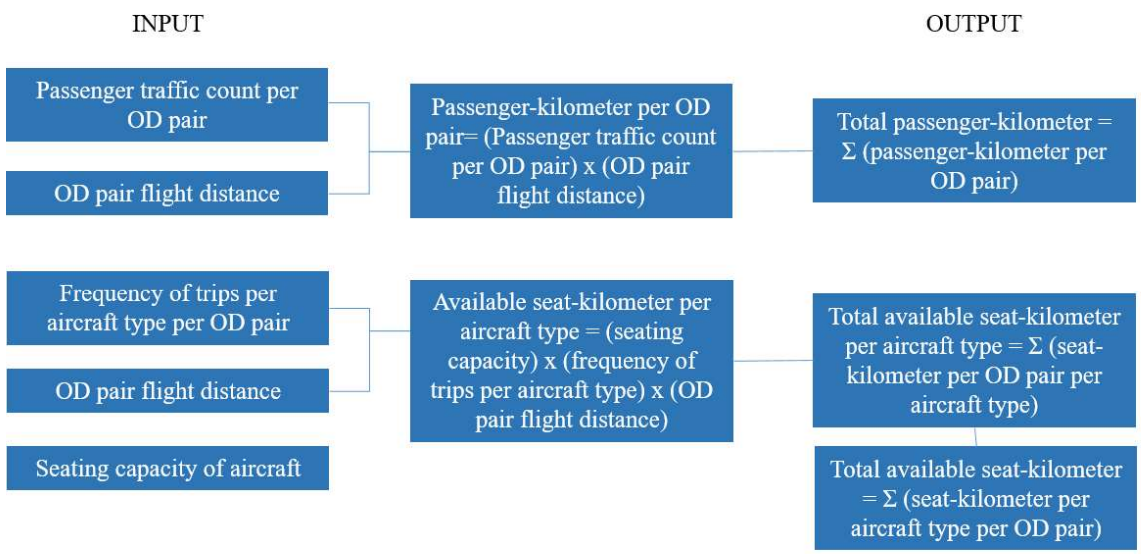

Figure 3. Flowchart for PKM and ASKM calculation

3.2 Input Data

3.2.1 Flight data

Domestic air transportation activity data were sourced from government agencies such as the Civil Aviation Authority of the Philippines (CAAP) and the Manila International Airport Authority (MIAA). However, upon initial inspection and analysis of their data, it has been found out that they are inadequate for bottom-up evaluation because some critical information such as aircraft type and origin and destination (OD) airports are not available.

Regidor (2019) assessed the transportation data and statistics in the Philippines for the four modes of transport: road, rail, air, and maritime. In his report, Regidor (2019) states that information significant to analysis and estimation of energy demand and emissions, such as OD pairs and their respective distances and aircraft types are not readily available from the current data collection system of some airport authorities in the Philippines. Regidor (2019) asserts that only the datasets from Mactan-Cebu International Airport and Clark International Airport contain the required information to estimate PKM travelled for air transportation. These details consist of aircraft origin and destination, departure and arrival times, and number of passengers. While these data are sufficient for a bottom-up estimation, the study aims to cover more domestic flights in the Philippines. Hence, the services of a third-party data provider, OAG Aviation Worldwide Pte. Ltd., have been procured to fill the data gaps.

The obtained flight data include departure and arrival airport names and codes, aircraft type, and frequency of domestic trips from 2010 to 2019. While the obtained flight data contain scheduled domestic flights, general aviation flights are not included in the datasets. As defined by ICAO (2009), general aviation flights are civil aviation operations other than scheduled and non-scheduled air transportation services for remuneration. This includes, but is not limited to, instructional flying, pleasure flying, business flying, corporate aviation, aerial work, and agricultural flying. Therefore, the estimation of energy demand in this study is limited only to the coverage of the flight data.

3.2.2 Passenger traffic data

Data on domestic scheduled passenger traffic per route from 2010 to 2019 have been obtained from the website of the Civil Aeronautics Board (CAB).

3.2.3 Flight distance estimation

A copy of the Philippine Enroute Chart has been secured from the CAAP to estimate flight distance. The chart displays airports connected by ATS routes with a configuration that shows the route name or designator, the minimum flight level for the route, and the distance of the route in nautical miles. The flight distance between two airports is computed as the sum of the route distances of the series of ATS routes connecting the OD pair. The series of ATS routes considered for the flight distance between an OD pair belongs to the shortest possible path. However in an actual situation, the flight path depends on the pilot's flight plan.

It is important to note that some airports on the chart do not have a direct ATS route connecting to/from them, such as Bacolod, Roxas, and Iloilo airports. Therefore, to estimate the flight distance for OD pairs with these airports, the scale on the chart is used to measure the distance from the compulsory ATS reporting point depending on the shortest possible path.

Still, there are data gaps in the flight distances because some airports are not included on the Philippine Enroute chart. To fill these gaps, each airport involved in the flight data from 2010 to 2019 is plotted in Google Maps, a web mapping and navigation software, to obtain their latitude and longitude coordinates. The airports' coordinates are then plotted in the geographic information system (GIS) software, Google Earth Pro. Finally, the configurations of the line of measurement are adjusted. The absolute elevation of the line of measurement is 32,000 feet or 9753.6 meters to consider the effect of the earth's shape and flying at an altitude in the flight distance estimation. Moreover, the elevation of 32,000 feet is based on the assumption that most flight distances are less than 500 nautical miles. At these distances the most frequently observed flight level is 32000 feet for most aircraft types in the flight data.

Since an actual flight does not follow a straight path from its origin airport to its destination airport, correction factors are applied to the obtained flight distances. The distances obtained from the GIS software are assumed as great circle distances (GCD) to utilize the GCD correction factors from the ICAO Carbon Emissions Calculator methodology in Table 2. Table 3 lists the estimated flight distances of some domestic routes in the Philippines. Figure 4 displays the routes estimated using Google Earth Pro.

Table 3. Estimated flight distances of domestic routes

Departure	Arrival	Flight distance (nm)	Flight distance (km)	Path
BCD	CEB	62.50	115.75	BCD-DELOR-MCT
BCD	CGY	178.00	329.66	BCD-DELOR-LOWAY-FORTA-CGO
CBO	CEB	188.00	348.18	COT-SIKIN-FORTA-COBOL-MCT
CEB	CRK	357.50	662.09	MCT-MOLOC-SAGRA-CONDE-CIA
CEB	WNP	257.00	475.96	MCT-PONSO-TAC-MALAG-LP-NGA
CGY	ZAM	207.00	383.36	CGO-COT-ZAM
CRK	BAG	98.35	182.14	Google Earth Pro + correction factors

CRK	BSO	354.00	655.61	CIA-MALIB-SANRO-LAO-ABVAR-BS
CRK	TAC	356.00	659.31	CIA-ALBAT-LOPEZ-MASBA-TAC
CYU	PPS	179.51	332.44	Google Earth Pro + correction factors
CYZ	CRK	128.50	237.98	CUY-CAB-CIA
CYZ	MNL	154.00	285.21	CUY-CAB-MIA
DVO	WNP	423.00	783.40	DAO-BN-TAC-MALAG-LP-NGA
DVO	ZAM	220.00	407.44	DAO-KLAFU-LINAO-COT-ZAM
ENI	CEB	302.07	559.44	Google Earth + correction factors
GES	ZAM	188.00	348.18	GSA-TBOLI-SEBUL-COGEL-ZAM
ILO	TAC	159.50	295.39	IOO-PARAO-PONSO-TAC
JOL	ZAM	108.72	201.35	Google Earth Pro + correction factors
KLO	CEB	128.50	237.98	KLO-BUNGA-DELOR-MCT
KLO	CRK	282.50	523.19	KLO-SAJ-TELEN-OLRAX-LUBAN-CIA
MNL	VRC	221.78	410.73	Google Earth Pro + correction factors
MNL	WNP	143.00	264.84	MIA-TIMON-LOPEZ-RAGAY-NGA
RXS	CEB	107.00	198.16	ROX-ATRIA-CADIZ-PARAO-MCT
RXS	MNL	240.50	445.41	ROX-SAJ-TAPAP-VERDE-TAALA-MIA
RZP	MNL	251.95	466.61	Google Earth Pro + correction factors
SJI	MNL	128.00	237.06	SAJ-TAPAP-VERDE-TAALA-MIA
TWT	ZAM	205.42	380.43	Google Earth Pro + correction factors
USU	CEB	280.43	519.36	Google Earth Pro + correction factors
WNP	MNL	143.00	264.84	NGA-RAGAY-LOPEZ-TIMON-MIA
ZAM	CBO	129.00	238.91	ZAM-COT
ZAM	TWT	205.42	380.43	Google Earth Pro + correction factors

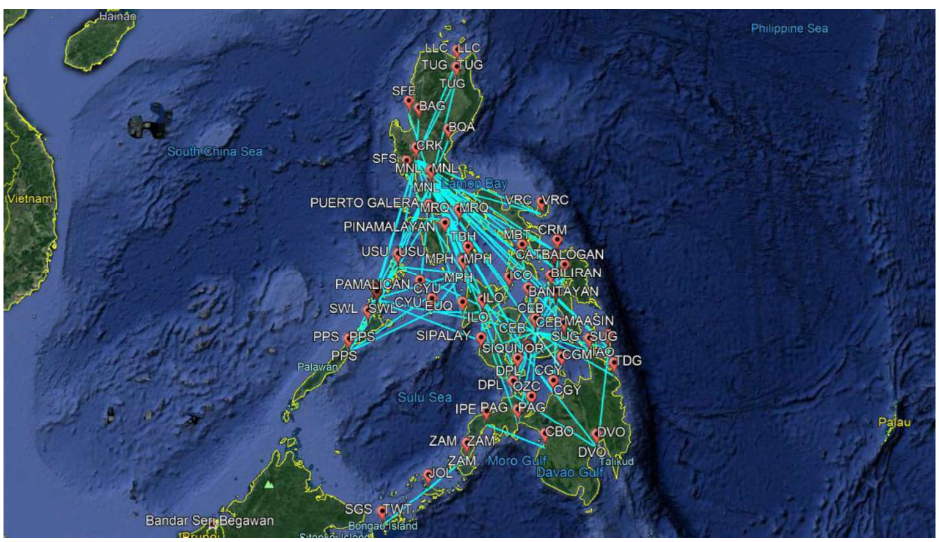

Figure 4. Flight distance estimation on Google Earth Pro (Google Earth Pro, 2015)

3.2.4 Aircraft information and fuel consumption factors

Each aircraft type in the flight data from 2010 to 2019 is mapped into its equivalent aircraft type, if necessary, because some types are still not included in the Master Emission Calculator by EEA/EMEP. The equivalent aircraft type must have its details in the Master Emission Calculator. The Doc 8643 – Aircraft Type Designators of ICAO (2020) is the main reference for the rationale of identifying the equivalent aircraft type, while other sources specific to some aircraft types are also used for those types whose manufacturer is not included in the Master Emission Calculator.

Aircraft information in the Master Emission Calculator includes the manufacturer, engine type, number of engines, and LTO and CCD fuel consumption factors (EEA, 2019). The most common engine ID in 2015, which was used for modeling in the Master Emission Calculator and one of the models associated with the equivalent aircraft type, are also included in the Aircraft Database. The LTO factor is expressed in kilograms, and the CCD factor is in kilograms as well but depends on flight distance in nautical miles. Interpolation in the table of flight distance and fuel burn per aircraft type using the estimated flight distance of an OD pair is needed to determine the appropriate CCD factor per OD pair per aircraft type.

The seating capacity of each aircraft type is sourced from the fleet data of some airline companies in the Philippines and the aircraft database of EUROCONTROL. The calculations also assume one seat class for the seating capacity of each aircraft type.

4. RESULTS AND DISCUSSIONS

Figure 4 illustrates the bottom-up estimation results as the sum of fuel consumption during LTO and CCD per year. The average shares of the fuel consumed during LTO and CCD to the total fuel consumption are 27.93% and 72.07%, respectively. From 2010 to 2019, the average annual growth rate of energy demand is 5.14%, which peaked at 15.14% from 2011 to 2012.

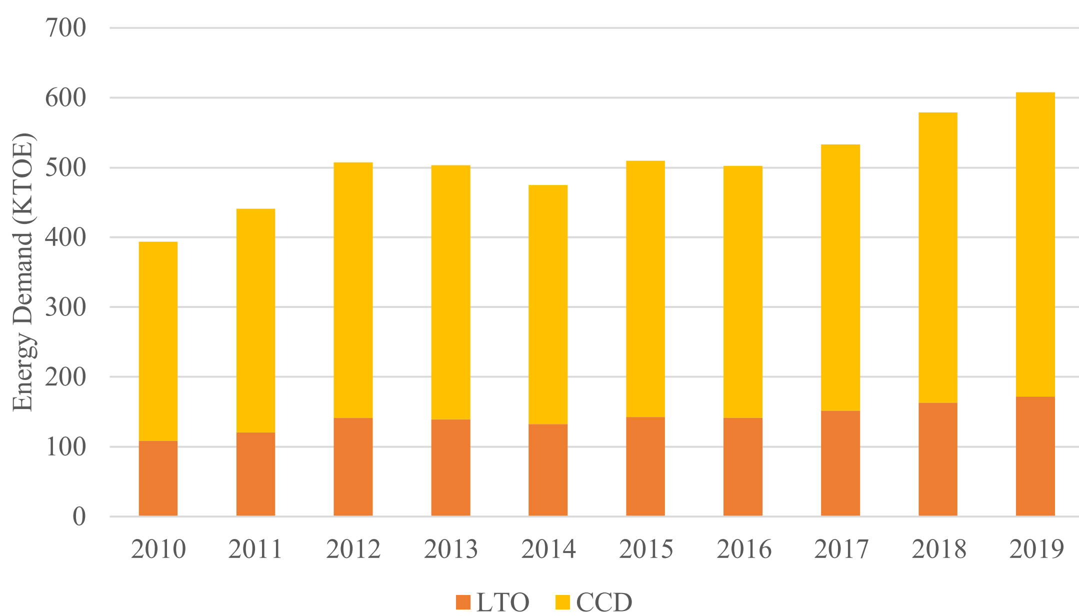

Figure 4. Results of bottom-up calculations

To compare the results of the bottom-up estimation with the statistics of DOE, the air transportation energy demand statistics for the years 2010 to 2016 are obtained from the TFEC of the air transportation sector in the Compendium of Philippine Energy Statistics and Information of DOE (2018). For 2017 and 2018, the demand is sourced from the Primary Energy Supply Mix of DOE (2019), while the statistics for 2019 is derived from the 2019 Petroleum Demand by Industry by Sub-sector and Fuel Type of DOE (2020). Moreover, DOE (2016) disaggregates the TFEC of air transportation into two fuel types: jet fuel and aviation gas. On the other hand, the calculations assume that all aircraft types consume jet fuel only.

Overestimation ranging from 37% to 67% percent difference from the DOE statistics can be observed from 2010 to 2012. This reduced to an average percent difference of 14.59% from 2013 to 2016. These deviations could be attributed to the differences in the engine specifications for modeling of fuel consumption factors and the actual engines because EEA (2019) utilized the most common engine ID in 2015 in their model. Locally established fuel economies could have better represented the Philippines' actual air transportation conditions, but unfortunately, they are not yet available. Meanwhile, significantly lower differences, around 1% to 5%, are noticed for the estimated demand from 2017 to 2019. Table 4 summarizes the percent difference per year, while Figure 5 displays the comparison of the estimates with the statistics.

Table 4. Comparison of results with the DOE statistics

Year	Bottom-up calculations (KTOE)			DOE (kTOE)	Percent difference
	LTO	CCD	Total		
2010	108.46	285.07	393.52	236	66.75%
2011	120.79	319.89	440.68	307	43.54%
2012	141.11	366.30	507.41	370	37.14%
2013	139.12	364.05	503.17	433	16.21%
2014	132.30	342.39	474.69	542	-12.42%
2015	142.80	367.05	509.85	446	14.32%
2016	141.42	360.94	502.36	594	-15.43%
2017	151.58	381.56	533.14	512	4.13%
2018	162.86	416.12	578.97	584	-0.86%
2019	171.83	435.86	607.69	579.85	4.80%

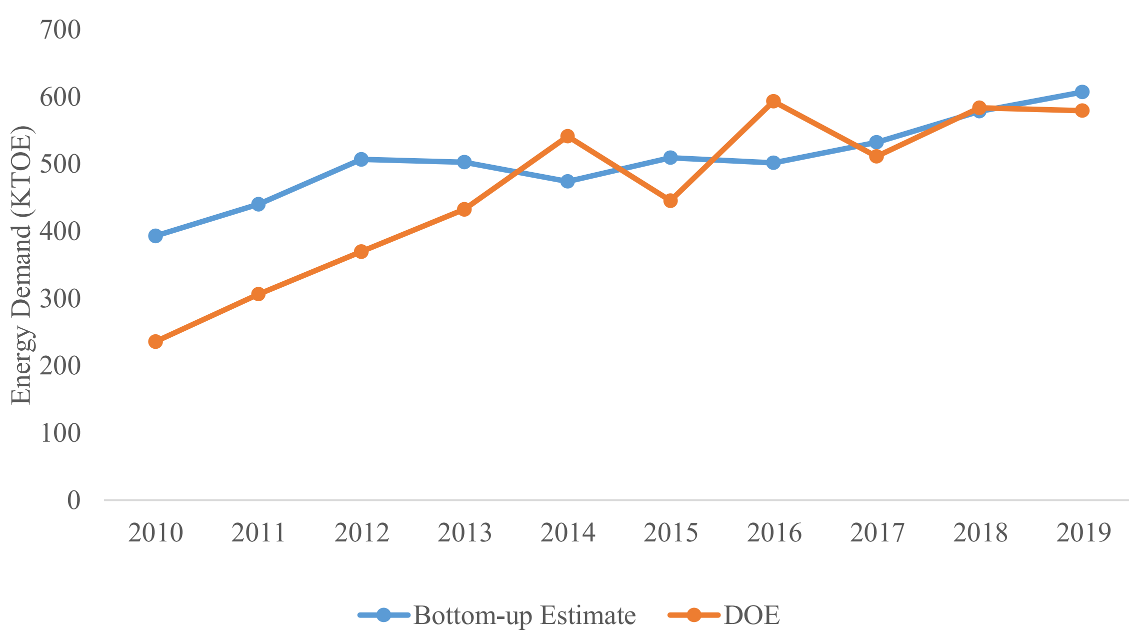

Figure 5. Calculated energy demand vs DOE statistics

Even though some flight distances are from the Philippine Enroute Chart, possible inaccuracies in the estimation of flight distance could also have attributed to the discrepancies between the results of bottom-up estimates and the DOE statistics because an actual flight path still depends on the flight plan as well as other conditions such as air traffic congestion in airports.

Another factor that might have affected the results is the difference in the coverage of flight data used in the estimation and the DOE statistics. As discussed in section 3.2.1, the obtained flight data contain scheduled domestic flights only. Upon inspection and analysis of aircraft movement data from 2010 to 2018 of the CAAP, military aircraft and general aviation flight operations show a significant share of the total aircraft movements. Flights to and from community airports that are not covered in the obtained data are also included in the annual aircraft movement count.

Both passenger-km and available seat-km display an increasing trend from 2010 to 2019, as seen in Figure 6. The quotient of PKM divided by ASKM gives the average passenger load factor. Figure 7 shows the average annual passenger load factor from 2010 to 2019, ranging from 74% to 93%. The average annual growth rate of passenger load factor from 2010 to 2019 is 1.56%. An increase in passenger load factor suggests that more seats are being filled up in a flight, thus reducing each passenger's carbon footprint in a flight. It is important to note that PKM has a different coverage of data compared with the energy demand estimates and ASKM because passenger traffic data are sourced from CAB. The energy demand estimates and ASKM, on the other hand, have the same scope as the flight data have.

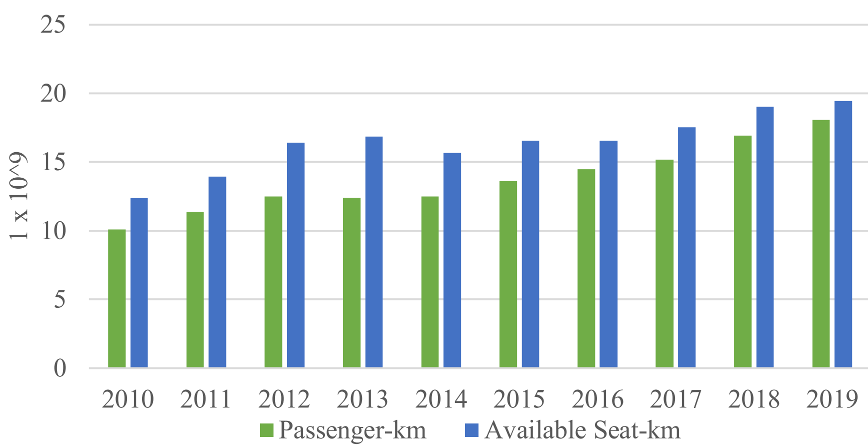

Figure 6. Passenger-km and available seat-km

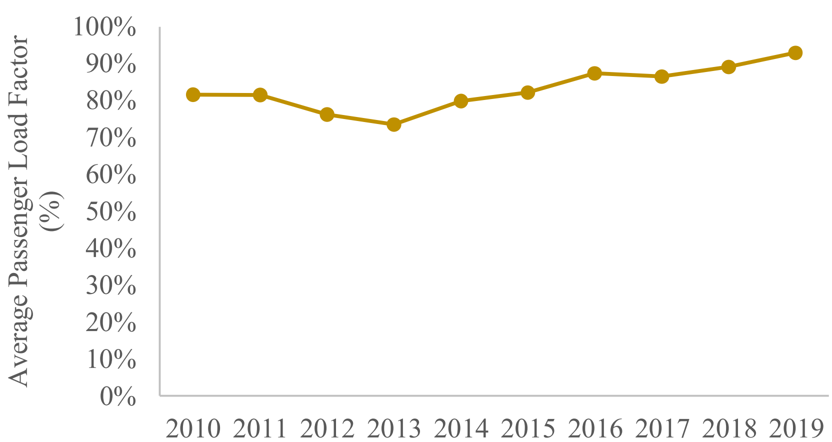

Figure 7. Average annual passenger load factor

The average fuel efficiency per year is expressed as passenger-kilometers per liter of fuel or PKM/L. Based on the calculations, aircraft operations in 2019 are the most fuel-efficient, with 23.79 PKM/L. On the other hand, the least fuel efficiency is observed in 2013 with 19.69 PKM/L. From 2010 to 2019, the average increase in PKM/L is 1.72%, which indicates that the domestic aircraft operations are gradually leaning towards fuel efficiency. This trend follows what ICCT (2015) claims, which states that commercial aircraft inclines towards fuel efficiency through time based on historical trends.

However, the average fuel efficiency in PKM/L in the transpacific airline industry is 31 PKM/L in 2016 according to ICCT (2018). While ICCT (2018) considered only flights from the United States to East Asia and Oceania in their calculations, the computed fuel efficiency in 2016 is still around 26% lower than the average fuel efficiency that year. Meanwhile, ICCT (2018) reports that the fuel efficiency of Philippine Airlines is 30 PKM/L for its flights from the US to East Asia and Oceania in 2016. ICCT (2018) concludes that the key drivers of fuel efficiency include freight share, seating density, aircraft fuel burn, and passenger load factor.

Table 5. Domestic air transportation activity

Year	Total number of trips	Passenger traffic	Total PKM (1×10^9)	Total ASKM (1×10^9)	Passenger load factor	PKM per liter
2010	174,456	16,568,308	10.09	12.36	0.82	20.53
2011	182,670	18,640,644	11.38	13.95	0.82	20.67
2012	207,551	20,568,392	12.51	16.41	0.76	19.73
2013	201,118	20,350,816	12.38	16.83	0.74	19.69
2014	191,267	20,352,810	12.51	15.65	0.80	21.09
2015	198,796	22,082,045	13.61	16.55	0.82	21.37
2016	198,104	23,430,995	14.47	16.56	0.87	23.06
2017	212,920	24,781,929	15.17	17.53	0.87	22.78
2018	231,355	27,283,603	16.93	19.00	0.89	23.42
2019	246,377	29,535,606	18.06	19.42	0.93	23.79

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Using secondary flight data, fuel consumption factors from secondary sources, and estimated flight distances, the Philippine air transportation energy demand is estimated to range from 394 to 608 KTOE for the years 2010 to 2019 with an average relative difference of 21.56% from the official energy statistics of the Department of Energy (DOE). While the results of this bottom-up estimate have deviations from the DOE statistics, particularly in 2010 to 2012, significantly lower discrepancies are observed for the results in the recent years 2017 to 2019. The average fuel efficiency per year ranges from 19.69 to 23.79 PKM/L from 2010 to 2019. The average fuel efficiency from 2010 to 2019 increases with an average growth rate of 1.72% which suggests gradual leaning towards fuel efficiency.

Data gaps were observed during data collection and the bottom-up estimation. One of the major difficulties in the bottom-up estimation is the lack of locally developed aircraft fuel economies. While the fuel consumption factors utilized in the calculations are established by international aviation organizations, local fuel economies could better manifest actual flight conditions in the country. The coverage of the datasets and the method of flight distance estimation used in the calculation could have attributed to the differences between the bottom-up estimate results and the official statistics. Comprehensive OD data including general aviation flights could improve the coverage of the bottom-up estimate, as well. While the CAAP and other airport authorities keep records on aircraft, passenger, and cargo movements, an available complete flight dataset with OD airports, aircraft type, flight distance, and frequency is still preferred to sourcing the data internationally for a bottom-up estimation.

5.2 Recommendations

Further studies on flight distance estimation are recommended to increase the accuracy of fuel consumption computation in CCD. Also, the development of local models, including freight tonnage, local standard cabin layout of aircraft, and the number of passengers, aside from fuel economies, would better describe aircraft fuel efficiency in the Philippines. These components are relevant in quantifying fuel efficiency, according to ICCT (2018). Moreover, the estimation of greenhouse gas emissions using the results of this study is suggested.

As the Philippine Department of Energy (DOE) encourages participation from public and private sectors in energy demand management (DOE, 2017), local airline companies and aviation-related government agencies can work together on extensive studies on fuel economies. The cooperation from both public and private sectors is crucial in establishing reliable and comprehensive data on the Philippines' operating air fleet, developing definite targets and implementing standards, policies, and programs on energy efficiency.

The World Bank (2012) recommends further studies on factors affecting energy efficiency in air transportation, such as aircraft design, operational efficiency, and infrastructure efficiency to develop a comprehensive bottom-up energy demand model for air transportation. It also encourages governments to invest in research and development on sustainable development schemes such as energy efficiency and greenhouse gas emissions reduction.

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