THE ENVIRONMENTAL COSTS OF PERU'S DOMESTIC AIR TRANSPORT: AN APPRAISAL

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Enzo DEFILIPPI

Abstract

The purpose of this paper is to estimate CO_2 emissions from Peru's domestic air transport. This is basic and relevant information for public policy making that has not been calculated before. The estimation has been performed using destination, frequency and aircraft related data of all domestic flights that departed or landed at Jorge Chavez International Airport, a hub that accounts for over 93% of the country's domestic air passenger traffic. CO_2 emissions were estimated using a methodology proposed by the International Civil Aviation Organization that differentiates fuel usage during each phase of a flight.

Results show that, in 2014, Peruvian domestic air transport was responsible for emitting approximately 606,975 tons of CO_2. This is equivalent to US$4.35 million or US$59.4 per one-way flight. These results could be used as an input to assess how to internalize the externalities caused by air transport to society and thus, to improve the efficiency and effectiveness of the country's environmental policy.

Keywords: air transport, CO_2 emissions, environmental regulation, environmental taxation

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1. Introduction

Since 1950, global air transport of passengers and freight has grown at rates of approximately 5% and 6% per year, respectively. If demand continues at this pace, it would double every 14 years for passenger services and every 12 years for freight operations. In absence of any change, the environmental impact of aviation would grow at similar rates (Schäfer and Waitz, 2014). Currently, aviation accounts for around 2% of all human-induced CO_2 emissions, which, in 2015, rose to 781 million tons (ATAG, 2010).

Aviation also contributes to climate change by non-CO_2 impacts, such as ozone and methane changes from NO_x emissions or contrails and contrail cirrus. While many countries have started to regulate CO_2 emissions, there are few that regulate non-CO_2 effects, probably because aviation-induced clouds and the effects of NO_x emissions at cruise altitudes are not fully understood by the atmospheric sciences (Scheelhaase et al., 2016).

Technology improvements facilitate air transport by reducing costs and lowering emissions of hazardous gases (Gardi, Sabatani, & Ramasamy, 2016; Strohmeier, et al., 2014). This has allowed airlines to increase the frequency of flights in certain routes and to improve the connectivity of air transport's complex network. (Lin & Ban, 2014).

However, more sound policies are needed to mitigate the impact of air transport in the environment. To produce these policies, better information regarding these effects is needed. This need is more urgent in the developing world, where problems regarding the lack of data and information are largely known.

The purpose of this paper is to estimate CO_2 emissions from Peru's domestic air transport.[1] This is basic and relevant information for public policy making, that has not been estimated before. Results could be used as an input to assess how to internalize the externalities caused by air transport to society and thus, to improve the efficiency and effectiveness of the country's environmental policy.

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[1] Commercial flights that depart and land within the country. This definition excludes civil aviation.

Estimations have been performed using route, frequency and aircraft related data of all domestic flights that departed or landed at Jorge Chavez International Airport (JCIA) in 2014; a hub that accounts for over 93% of the country's domestic air passenger traffic. CO_2 emissions were estimated using a methodology proposed by the International Civil Aviation Organization (ICAO) that differentiates fuel usage during each phase of a flight. Results were later converted into their monetary equivalent using Peru's official shadow price of carbon—an input used for the evaluation of the country's public investment projects.

The following section presents a brief literature review of the topic. The third section discusses the importance of JCIA for Peru's domestic air transport, and presents the methodology and the data. The fourth section presents the results and the fifth, a sensitivity analysis of the estimation. Finally, section six presents the conclusions of this paper.

2. Literature review

There are few studies that analyze the environmental effects of aviation or propose public policies to address this subject.

Schipper (2004) analyzes the impact of airports' operations on both air pollution, noise nuisance and accident risk studying a sample of European airline markets. Results suggest that environmental costs represent only a small fraction (2.5%) of the internal cost of aviation as measured by the average ticket price. Noise costs represent 75% of the total.

Both the studies by Givoni and Rietveld (2010) and Lu and Morrell (2006) analyze the environmental costs of air transport. The former studies the costs of linking two pair of cities (London-Amsterdam and Tokyo-Sapporo) using two different types of aircraft. Results show that increasing aircraft size and adjusting the service frequency to offer similar seating capacity will increase local pollution but decrease climate change impact and noise pollution. The latter estimate the local environmental costs of noise and pollution of a sample of European airports (Schipol, Maastricht, Stansted, Heathrow and Gatwick). Results indicate that the relationship appears to be curvilinear between environmental costs and the traffic volume of an airport.

Morrell and Lu (2007) study a small sample of eight airports and compare the environmental costs of two different models of organizing the aviation activities: hub-to-hub versus hub-by-pass networks. It was found that the social cost impact (noise and emissions) of the hub-by-pass networks was significantly lower than the hub-to-hub in all cases. Differences in environmental costs per passenger depend on the concentration of population around the airports and the degree to which the hub routing involves extra mileage.

Scheelhaase et al. (2016) analyze the best option to address aviation's full climate impact. They devise four geopolitical scenarios that differ in the level of international support for climate protecting measures. Their results show that a global emissions trading scheme for the political regulation of both CO_2 and non-CO_2 emissions of aviation would be the best solution from an economic and environmental point of view. Costs and impacts on competition could be kept at a relatively moderate level and environmental benefits would be significant.

Grampella, Martini et al. (2017) analyze the annual amount of environmental outputs produced by all airports of a national system over time using a sample of Italian airports over a ten-year period. Authors estimate the environmental effects using certification data for each aircraft-engine combination, and take into account the amount of environmental effects that is internalized at the airport. Their results show that a 1% increase in airport's yearly movements yields a 1.05% increase in environmental effects, a 1% in aircraft size (measured in MTOW) gives rise to a 1.8% increase, and a 1% increase in aircraft age generates a 0.69% increase in environmental effects. More interestly, they find that the tariff that internalizes the total amount of externality is about €180 per flight, while the tariff limiting only pollution is about €60, and the one reducing noise is about €110.

IATA has proposed to reduce net aviation CO_2 emissions by 50% by 2050. Nevertheless, to reach this goal, the industry needs incentives to improve current technology, operations and infrastructure and to develop new technologies and biofuels.

Grampella, Lo et al. (2017), however, find that the emission reductions that have been achieved so far by technical progress don't offset the negative impact on CO_2 emissions caused by the increase in passenger and cargo traffic. In order for the IATA's objetive to be fulfilled, technological progress needs to occur at a faster pace and be accompanied with concomitant emission-reduction policies.

3. The environmental costs of Peru's domestic routes

The Peruvian aviation system

In Peru, domestic air passenger traffic amounts to around 9 million per year,[2] a figure that has grown at a rate of 15.26% per year between 2009 and 2015 (MTC, 2016). As shown in Table 1, 93.54% of the total (8.4 million) were handled at JCIA in 2014.

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[2] Commercial flights only.

Table 1: Peru and JCIA's domestic air passenger traffic, 2014

Traffic measure	#
Peru's domestic air passenger traffic (total)	8,950,165
JCIA's domestic air passenger traffic	8,371,733
JCIA's to Peru's domestic air passenger traffic	93.5%

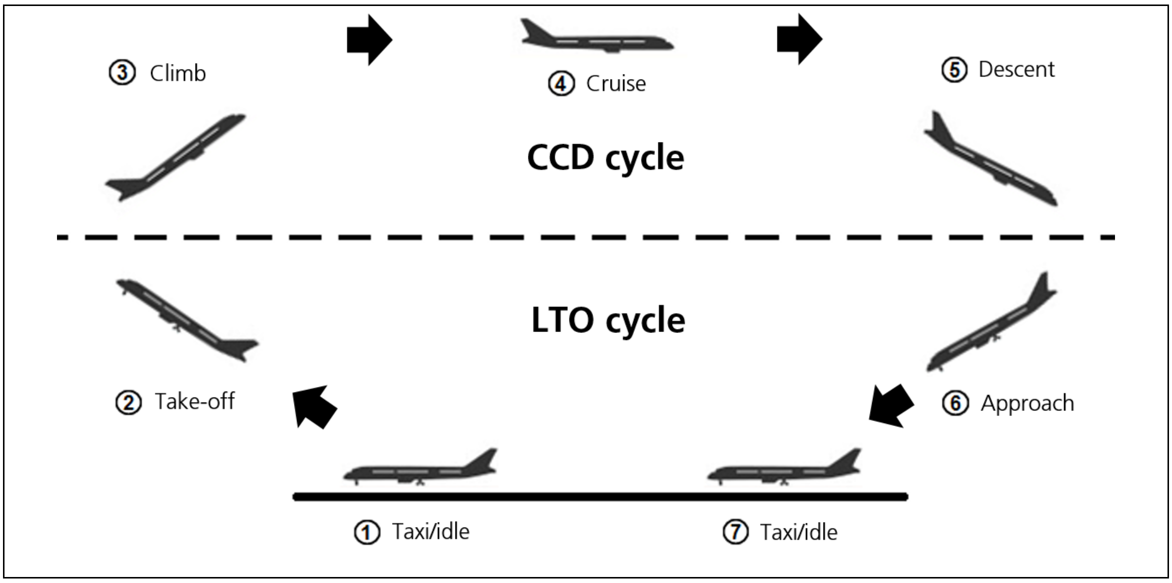
Given Peru's domestic air traffic concentration at JCIA, emission estimates for flights landing or departing at this airport can be considered a proxy for the country's total emissions.

Methodology

To quantify an aircraft´s emissions of gases to the atmosphere it is necessary to distinguish the different phases of a flight, given their differences in fuel usage.

According to the ICAO (2011), there are six key phases that take place during an aircraft´s departure and arrival: taxi/idle, take-off, climb, cruise, descent and approach. These can be grouped in two cycles: Landing and Take-off (LTO), which comprises the activities near the airport below 915m of altitude; and Climb-Cruise-Descent (CCD) which takes place at altitudes above 915m. Figure 2 illustrates them.

Figure 2: Aircrafts' flight phases



ICAO proposes a simple approach to calculate emissions of air pollutants during the different phases of a flight. A general formula estimates an aircrafts' emissions (AE) of pollutant i, produced by aircraft type j, in mode k with fuel f measured in kilograms (kg).

For take-off, climb and approach, the adopted specification multiplies the Time-in-mode[3] (TIM) of an aircraft type j in mode k, times fuel flow (FF) measured in kilograms per second (kg/s) of aircraft type j in mode k, times the emission index (EI) of pollutant i in kilograms per fuel type f kilograms. The resulting equation for the LTO cycle is:

$$AE_{i,j,k,f} = TIM_{jk} \times FF_{jk} \times EI_{if}$$

For the CCD cycle, a different formula has to be used since fuel consumption is affected by phase, speed and distance. It is worth noting that, even though it is known that fuel consumption during climbing is higher than during cruising and that during cruising it is higher than during descending, neither the climbing nor the descending phase is standardized (ICAO, 2013). Therefore, assumptions need to be made regarding fuel consumption during both. In this case, it is assumed, for simplicity´s sake, that fuel consumption during climbing and descending averages consumption during cruising speed. Thus, CO_2 emissions during the CCD cycle will be estimated as if its full length was made in cruising mode. This assumption, which will probably sub estimate results, will be later relaxed when performing a sensitivity analysis.

The formula for the CCD cycle estimates an aircrafts' emissions (AE) of pollutant i, produced by aircraft type j, in mode k with fuel f measured in kilograms (kg). This specification requires an estimation of fuel flow (FF) measured in kilograms per hour (kg/h) of aircraft type j in mode k, the emission index (EI) for the pollutant i in kilograms per liter (kg/l) of fuel type f, the density (Dens) of fuel f in kilograms per liter (kg/l) and the cruising speed (CS) of aircraft type j in kilometers per hour (km/h). The resulting equation is:

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[3] Time-in-mode (TIM) refers to the time that the engines spend at a certain power setting during the LTO operating mode (ICAO, 2011).

$$AE_{i,j,k,f} = \frac{FF_{j,k} \times EI_{i,f}}{Dens_f \times CS_j}$$

However, since in this case AE will only be estimated for CO_2 in cruise mode, the formula can be rearranged as:

$$AE_{CO_2,j,Cruise,f} = \frac{FF_{j,Cruise} \times EI_{CO_2,f}}{Dens_f \times CS_j}$$

This formula provides an estimate of CO_2 emissions for each different type of aircraft used for domestic flights. To estimate them for a whole year, each aircraft´s result should be multiplied by the distance of each route times the number of frequencies. If there are M routes, the annual aircraft emissions of CO_2, during cruise mode, measured in kilograms for a specific type of fuel f will be:

$$Total\ AE_{CO_2,Cruise,f} = \sum_{m \in M} AE_{CO_2,j,Cruise,f} \times Dist_m \times Freq_m$$

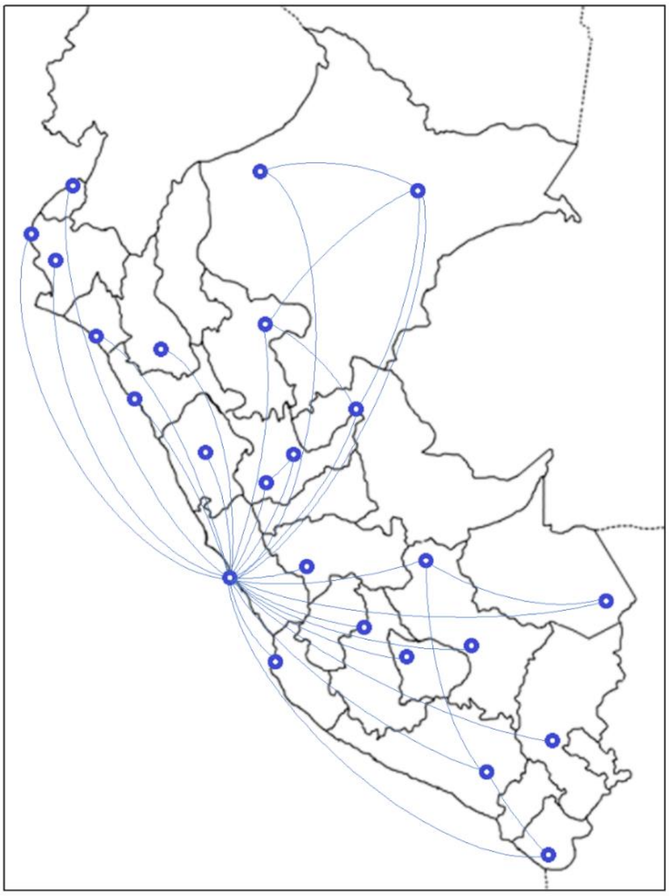
There is no consensus as on which type of fuel should be used for a certain type of airplane. For this estimation, we assume that kerosene is the fuel aircrafts use. According to the U.S Energy Information Administration (EIA), CO_2 emissions for every gallon of kerosene is 9.75 kilograms (EIA, 2016).

To estimate the economic cost CO_2 emissions cause to Peruvian society, the official proxy for the social cost of carbon (SCC), set by the Peruvian Ministry of Economics and Finance for the evaluation of public investment projects, was used. According to Nordhaus, social cost of carbon is defined as “the discounted value of the utility of consumption per unit of aditional emissions, denominated in terms of current consumption” (Nordhaus, 2014, p.273).

Data

In 2014, seven airlines that employed 17 different types of aircrafts (each with a distinct engine) operated domestic flights at JCIA. The engine type determines the fuel flow and the cruising speed of the flight, both inputs of the ICAO formula. The aircrafts' engine information was retrieved from the specific Pilot Operation Handbook (POH) of each aircraft type. The appendix shows average weekly frequencies per route and aircraft at JCIA in 2014. Distances between JCIA and each destination were calculated using the Haversine formula[4]. Figure 3 illustrates these routes.

Figure 3: Peru: Domestic routes departing or landing at JCIA (including layovers), 2014



4. Results

Table 2 shows the estimated CO_2 emission rate by aircraft type in kg/km.

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[4] The Haversine formula calculates the shortest distance over the earth's surface between two points, given their longitudes and latitudes (Mahmoud & Akkari, 2016).

Table 2: CO_2 emission rates by type of aircraft used for domestic flights in JCIA

IATA Code	Aircraft type	Engine type	CO_2 emission rate in cruise (kg/km)
319	Airbus-319	IAE V2524-A5	9.11
320	Airbus-320-232	IAE V2527-A5	9.61
E90	Embraer E190	GE CF34-10E	7.06
319	Airbus-319-132	IAE V2524-A5	9.11
320	Airbus 320-214	CFM56-5B4	9.61
141	BAE146-100	ALF 502	10.52
142	BAE146-200	ALF 502	10.59
143	BAE146-300	ALF 502R-7	10.73
732	Boeing-737-204	JT8D-219	10.40
732	Boeing 737-299	JT8D-219	10.40
732	Boeing-737-207	JT8D-219	10.40
732	Boeing-737-230	JT8D-219	10.40
733	Boeing-737-300	CFM56-3 B2	9.60
734	Boeing-737-400	CFM56-3 C1	10.40
DH3	DHC-8	PW120A	5.39
PAY4	Piper Cheyenne III	PT6A-41	2.24
BEH	Beechcraft-1900	PT6A-65B	2.18

Source: ICAO, 2011. Own calculations.

Results show that CO_2 emissions from Peru's domestic air transport totaled 606,975 tons in 2014, approximately. As shown in Table 3, three quarters of the total are produced during the CCD cycle.

Table 3: Peru: CO_2 emissions caused by domestic air transport per flight phase, 2014

Flight phase	Tons
Total CO_2 emissions in CCD cycle	460,387
Total CO_2 emissions in LTO cycle	146,588
Total	**606,975**

This result was later converted into their monetary equivalent using Peru's official shadow price of carbon, which amounts to US$7.17 per ton (MEF, 2017). As shown in Table 4, the monetary value of this externality amounts to US$4,352,011, which corresponds to an average of US$59.4 per one-way flight.

Table 4: Peru: monetary value of CO_2 emissions caused by domestic air transport

Definition	US$
Social cost of total CO_2 emissions	4,352,011
Average SCC per flight	59.4

It is worth noting that this result is consistent with that of Grampella, et al. (2017) who found that the tariff that internalizes the externality caused by pollution is about €60 per flight (US$66, approximately).

5. Sensitivity Analysis

Tables 5 and 6 show results when three basic estimation assumptions are relaxed: (i) distance flown corresponds to the shortest path between origin and destination, (ii) fuel consumption during the climbing and descending phases averages consumption during cruising, and (iii) kerosene is the best proxy to estimate fuel consumption by aircrafts covering Peruvian domestic routes.

Estimations show that with the above-discussed assumptions regarding fuel consumption, CO_2 emissions would amount to 629,994 tons (3.8% higher) if the distance flown in all routes is 5% longer. Likewise, that emissions would amount to 620,676 tons (2.3% higher) if fuel consumption were 3% higher during climbing than during descending, and that emissions would amount to 597,935 tons

(1.5% lower) if jet fuel use is assumed instead of kerosene. Table 5 show combinations of these assumptions.

Table 5: Peru: CO2 emissions (tons) caused by domestic air transport under different assumptions, 2014

		Distance flown	
		As estimated	5% longer
Fuel consumption	As estimated during climbing and descending	606,975	629,994
	3% higher during climbing and descending	620,676	644,381
	Jet fuel instead of kerosene	597,935	620,503

Table 6 shows the average social cost of carbon per flight in each of these scenarios. It would amount to US$61.2 if the distance flown in all routes were 5% longer, to US$60.7 if fuel consumption were 3% higher during climbing than during descending, and to US$58.5 if use of jet fuel was assumed.

Table 6: Peru: monetary value of CO_2 emissions caused by domestic air transport under different assumptions, 2014

		Distance flown	
		As estimated	5% longer
Fuel consumption	As estimated during climbing and descending	US$59.4	US$61.6
	3% higher during climbing and descending	US$60.7	US$63.0
	Jet fuel instead of kerosene	US$58.5	US$60.7

6. Conclusions

The purpose of this paper is to quantify CO_2 emissions from Peru's domestic air transport. This is basic and relevant information for public policy making that has not been calculated before.

Estimations have been made using destination, frequency and aircraft data of all domestic flights that departed or landed at Chavez International Airport, a hub that accounts for over 93% of the country's domestic air passenger traffic. CO_2 emissions were estimated using a methodology proposed by the International Civil Aviation Organization (ICAO) that differentiates fuel consumption during each phase of a flight.

Results show that, in 2014, Peruvian domestic air transport was responsible for emitting approximately 606,975 tons of CO_2, equivalent to US$4.35 million or US$59.4 per one-way flight. The latter figure could be as low as US$58.5 or as high as US$63 depending of the assumptions made. These estimations are consistent with estimations made for other countries.

Results could be used as inputs to assess how to internalize the externalities caused by air transport to society and thus, to improve the efficiency and effectiveness of the country's environmental policy.

Further research is needed to estimate non-CO_2 effects of domestic air transport and those produced by Peruvian international passenger traffic.

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Appendix

Peru's domestic air passenger traffic: Average weekly frequencies per destination and aircraft at JCIA, 2014

Destination	Aircraft	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Andahuaylas	DHC-8	5	6	6	6	7	7	7	7	7	7	7	7
Anta	DHC-8	7	3	3	3	4	6	7	7	7	7	7	3
Arequipa	Airbus-319-132 / Airbus 320-214	48	51	48	47	54	53	58	63	57	57	57	55
Arequipa	Airbus-320-232	9	9	7	7	7	7	7	7	7	7	7	7
Arequipa	Boeing-737-300 / Boeing-737-400	13	14	14	14	14	14	14	14	14	14	14	13
Arequipa (via Cuzco)	Airbus-319-132	0	0	2	4	4	4	6	7	5	7	5	4
Ayacucho	Airbus-319-132	0	0	0	0	0	0	0	0	0	3	3	3
Ayacucho	BAE146-100 / BAE146-200	6	7	7	6	7	7	7	7	7	9	9	7
Ayacucho	DHC-8	12	14	14	14	13	13	14	14	14	13	14	14
Cajamarca	Airbus-319-132	18	20	20	19	21	18	20	19	20	19	19	18
Cajamarca	DHC-8	13	14	13	12	13	14	14	14	13	14	14	14
Chiclayo	Airbus-319-132 / Airbus 320-214	27	28	26	26	28	28	27	27	24	28	27	27
Chiclayo	Airbus-320-232 / Embraer E190	7	6	6	6	6	6	7	7	7	7	7	7
Cuzco	Airbus-319 / Airbus-320-232 / Embraer E190	32	24	20	26	26	25	25	26	26	26	26	26
Cuzco	Airbus-319-132 / Airbus 320-214	79	78	79	88	95	93	103	113	105	105	95	91
Cuzco	BAE146-100 / BAE146-200	12	13	13	15	14	21	21	23	21	18	15	15
Cuzco	Boeing-737-204 / Boeing 737-300	22	22	21	24	22	23	24	27	24	26	24	25
Cuzco	DHC-8	0	0	0	0	0	0	0	6	3	3	3	3

Destination	Aircraft	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cuzco (via Arequipa)	Airbus-319 / Airbus-320-232 / Embraer E190	7	7	7	7	7	6	7	7	7	7	7	7
Huánuco	DHC-8	6	7	7	7	7	7	7	7	7	10	13	12
Iquitos	Airbus-319 / Airbus-320-232	0	0	0	0	0	3	7	7	7	7	7	7
Iquitos	Airbus-319-132 / Airbus 320-214	38	40	34	32	33	36	37	35	34	35	32	37
Iquitos	Boeing-737-300 / Boeing-737-400	14	14	14	13	14	14	13	14	14	14	14	12
Iquitos (via Andoas)	BAE146-300 / BAE146-200	3	3	3	3	3	3	3	3	3	3	5	5
Iquitos (via Pucallpa)	BAE146-300 / BAE146-200	7	7	7	7	7	7	7	6	7	7	7	7
Iquitos (via Tarapoto)	BAE146-200 / BAE146-300	7	7	7	7	7	7	7	6	7	6	7	7
Jauja	DHC-8	0	0	0	0	0	0	0	0	2	3	3	3
Jauja	DHC-8	13	16	15	14	16	15	15	16	16	16	15	14
Juliaca	Airbus-319-132 / Airbus 320-214	16	18	16	17	17	17	16	16	16	16	14	14
Las Malvinas	BAE146-200 / BAE146-100	8	6	6	6	7	6	7	7	8	7	7	10
Las Malvinas	DHC-8	0	0	0	0	0	0	0	2	1	2	1	0
Las Malvinas	DHC-8	4	5	4	5	4	5	5	5	5	5	4	5
Las Malvinas	Piper Cheyenne III / Beechcraft-1900	3	1	0	2	1	2	3	2	1	1	2	1
Pisco	DHC-8	0	0	0	0	0	0	0	0	0	0	0	0
Piura	Airbus-319 / Airbus-320-232 / Embraer E190	14	16	13	13	14	13	13	13	13	14	13	13
Piura	Airbus-319-132 / Airbus 320-214	43	45	39	40	43	42	40	40	38	44	37	41
Piura	Boeing-737-204 / Boeing 737-	7	7	7	7	7	7	7	7	7	7	7	9

Destination	Aircraft	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	299												
Pucallpa	Airbus-319-132 / Airbus 320-214	16	18	14	17	17	18	18	19	18	19	19	19
Pucallpa	BAE146-200	4	5	5	5	3	2	6	1	3	1	1	1
Pucallpa (via Tarapoto)	BAE146-200 / BAE146-300	0	0	0	0	0	0	0	3	2	3	3	2
Puerto Maldonado	Airbus-319-132 / Airbus 320-214	6	5	5	6	7	6	7	7	7	7	7	7
Puerto Maldonado (via Cuzco)	Airbus-319-132	7	7	6	7	7	7	9	9	7	9	7	7
Puerto Maldonado (via Cuzco)	BAE146-100 / BAE146-200	7	6	7	7	7	7	7	7	7	7	7	7
Tacna	Airbus-319-132 / Airbus 320-214	18	21	17	19	18	17	18	19	20	18	18	17
Tacna (via Arequipa)	Boeing-737-230 / Boeing-737-300 / Boeing-737-400	10	11	10	10	10	10	9	11	11	11	11	10
Talara	Airbus-319-132	0	0	0	0	0	0	0	0	0	0	7	7
Tarapoto	Airbus-319-132 / Airbus 320-214	25	27	25	23	24	25	25	25	24	24	22	24
Tarapoto	Airbus-320-232 / Embraer E190	7	6	7	7	7	6	7	7	7	7	1	0
Tarapoto	BAE146-100 / BAE146-200 / BAE146-300	3	2	2	1	1	0	5	0	0	0	0	0
Tarapoto	Boeing-737-204 / Boeing-737-207 / Boeing-737-230 / Boeing-737-300	14	14	14	14	13	14	14	14	14	14	14	13
Tarapoto (via Pucallpa)	BAE146-200 / BAE146-300	0	0	0	0	0	0	0	3	2	2	2	2

Destination	Aircraft	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tingo Maria	DHC-8	6	9	8	7	9	7	7	7	7	7	7	7
Trujillo	Airbus-319 / Airbus-320-232 / Embraer E190	13	13	12	12	13	13	14	14	14	14	14	14
Trujillo	Airbus-319-132 / Airbus 320-214	26	28	24	22	26	26	26	27	27	26	27	26
Tumbes	Airbus-319-132 / Airbus 320-214	13	15	10	10	12	11	14	12	13	12	11	13

Source: MTC (2016)