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AIRPORT RELATED EMISSIONS AND THEIR IMPACT ON AIR QUALITY AT A MAJOR JAPANESE AIRPORT: THE CASE OF KANSAI INTERNATIONAL AIRPORT

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The objective of this study was to investigate the carbon dioxide (CO_2) emissions of an airport, to determine if strategies are helping to achieve sustainability targets. Kansai International Airport was selected as the case study, and it is Japan's third largest airport and there was readily available comprehensive data to enable a study to be undertaken. The airport has a dedicated environmental division and has implemented various initiatives over the past decade or so to reduce the airport's impact on the surrounding environment, especially since it is in Osaka Bay. The research used an exploratory design, with an initial qualitative case study, followed by a quantitative longitudinal study, utilizing correlation to assess trends over time. Results showed statistically significant reductions in carbon dioxide (CO_2) emission from the three facets of airport operations, both in terms of the number of passengers and number of aircraft serviced by the airport. As a result, the initiatives undertaken at Kansai International Airport could be adapted and used by other airports to help reduce their carbon dioxide emissions.

Keywords: airports, airport emissions, aircraft emissions, case study, Kansai International Airport, nitrous oxides

1. Introduction

On a world-wide basis, the environmental sustainability of air transport is receiving greater attention in recent times due to its critical impact on climate change (Teoh and Khoo, 2016). Aircraft operations at airports is a source of CO_2 emissions that influence climate and includes other pollutants that affect air quality as well as human health (Ashok *et al*., 2017; Budd, 2017). At the worldwide level, aircraft emissions contribute to climate change through the increase in the levels of greenhouse gases, such as CO_2 and H2O in the troposphere and the stratosphere (Marais *et al*., 2016). As well as their impact on air quality and human health concerns (International Civil Aviation Organization, 2019B), aircraft emissions have also contributed to ozone depletion and climate change (Zhang, 2015). Over the past decade or so, global airline traffic has dramatically increased which has resulted in a significant increase in emissions (Unal *et al*., 2005). Considering this impact, there has been growing pressure for the global aviation industry to reduce its CO_2 emissions (Grote *et al*., 2014; International Air Transport Association, 2018; Sgouridis *et al*., 2011).

In recent times, airports have also been under growing pressure to support the vision of a low carbon energy future (Ryley *et al*., 2013). Due to the growing amount of residential development that surround airports together with the continued growth of commercial air travel, air pollution surrounding airports is now increasingly regarded as significant concern for local/ regional governments (International Civil Aviation Organization, 2019b). Consequently, many airports around the world have defined and implemented extensive programs to mitigate the impact of carbon dioxide (CO_2) emissions (Mosvold Larsen, 2015).

The objective of this study is to empirically examine the aircraft and airport-related carbon dioxide (CO_2) emissions at Osaka's Kansai International Airport, Japan's third largest airport, and their impacts on air quality at the airport. A secondary aim was to examine the trends in methane and nitrous oxides (N2O) at the airport. Kansai International Airport (IATA Airport Code: KIX) was selected as the case airport as it is a key hub airport, served by both full-service network carriers (FSNCs) and low-cost carriers (LCCs) as well as freighter aircraft operators, that has been committed to sustainable operations throughout its history. The availability of a comprehensive data set covering the period 2006 to 2016, was a further factor in selecting Kansai International Airport as the case company.

The remainder of the paper is organized as follows: Section 2 sets the context of the case study by providing a review of the extant literature on airport-related emissions and their impact on air quality. The research method that underpinned the study follows in Section 3. The case study is presented in Section 4. Section 5 presents the key findings of the study.

2. Background

2.1. Local air quality at airports

An airlines' CO_2 emission profile is dependent on a range of factors including but not restricted to the aircraft deployed, the aircraft's payload, air route taken, and prevailing weather conditions (Yin *et al*., 2015). The worldwide aviation industry relies almost solely on the combustion of carbon-based fossil fuels, principally kerosene. When the fuel is burnt in the aircraft engines, jet fuel emits a variety of greenhouse gases, including carbon dioxide (CO_2), nitrous oxides as well as water vapor (Budd, 2017; Janić, 2011).The level of carbon dioxide (CO_2) emissions is a product of hydrocarbon combustion and the amount of these gases is consequently directly related to the volume of fuel consumed, which in turn is a function of the aircraft and its engine fuel efficiency, together with the length of time that an aircraft's engines or auxiliary power unit (APU) are running (Marais *et al*., 2016).

The sources of emissions at an airport normally include the following:

- Aircraft emissions: are a function of the number of annual aircraft movements at the airport, the aircraft fleet mix, that is, the types of aircraft and their engines serving an airport, and the length of time that an aircraft spend in various modes of the landing and take-off cycle. Six aircraft operating modes constitute a landing/take-off (LTO) cycle: first, the actual approach to the airport, second, the landing roll on the runway, third, taxi from the runway to the parking gate or apron stand, fourth, taxi out from the gate or apron stand to the runway, fifth, take-off on the runway, and sixth, climb-out from the airport (Culberson, 2011).
- An auxiliary power unit (APU): these units supply the essential power requirements for an aircraft whilst it is on the ground in between flights. They are used when the main engines are not running or there is no other alternative power source. An auxiliary power unit (APU) are small gas turbine engines that are typically mounted in the rear of the fuselage (Smith, 2004). Because jet fuel is utilized as the power source for APUs, they emit exhaust gases (Culberson, 2011).
- Ground support equipment: such as aircraft push-back tugs, aircraft loaders, catering trucks and the tugs that haul passenger baggage and air cargo, also create exhaust emissions. In addition, passengers, airport employees, hotel and rent-a-car shuttle buses, and suppliers (Culberson, 2011) all generate motor vehicle traffic on airport roadways and in car parks that can be a significant source of pollutant emissions at an airport.
- Construction emission sources: can include the vehicles and equipment used in construction projects, land development activities, asphalt paving activities, asphalt batch plants, and painting activities. These vehicles and equipment generate pollutant emissions at the airport.
- Stationary sources: can include heating and cooling plants, emergency power generators, and other industrial facilities located within the airport precinct (Culberson, 2011).

Thus, gaseous emissions of CO_2, as well as carbon monoxide (CO) and nitrous oxide (N2O) and particulates (PMs) from aircraft, ground access transport, such as buses and taxis, power generation and on-airport ground transport vehicles, all negatively impact local air quality (Budd, 2017). Budd (2017) has noted that "poor air quality has potential health implications for people living and working around airports, in terms of increased risk of contracting or exacerbating existing cardiorespiratory conditions". In addition, air pollution causes damage to soil, water, vegetation, wildlife, animals and a deterioration of property (and property values) as a well as causing a reduction in the visibility which results in the losses of aesthetic appeal and increased hazards in transportation. Hub airports with a substantial volume of commercial jet aircraft may significantly contribute to this problem (Horonjeff *et al*., 2010).

Thomas and Hooper (2013, p. 557) have observed that "evidence suggests that the operation of an airport can be the most significant source of some pollutants in a particular locality and that while on the airport itself, aircraft emissions dominate, and in the area surrounding airports, road traffic can be the main source". Due to the growing amount of residential development that surround airports together with the continued growth of commercial air travel, air pollution surrounding airports is now increasingly regarded as significant concern for local/ regional governments (International Civil Aviation Organization, 2019a). Consequently, many airports around the world have defined and implemented extensive programs to mitigate the impact of carbon emissions (Masiol and Harrison, 2014).

2.2. Limiting aircraft emissions through technology

As previously noted, there are various emissions from aircraft engines that impact air quality (Bo *et al*., 2019; International Civil Aviation Organization, 2016). These emissions include nitrogen oxides (NOx), carbon monoxide (CO), sulphur oxides (SOx), unburned hydrocarbons (HC), smoke and particulate matter (PM) (Graham, 2018; International Air Transport Association, 2019). In recent times, improved aircraft engine designs have gradually reduced the emissions of NOx and CO and have virtually eliminated emissions of unburned hydrocarbons (HC) and smoke (International Air Transport Association, 2019). Indeed, LTO oxides of nitrogen (NOx) have been reduced by 75% since 2010. In addition, carbon dioxide (CO_2) has been reduced proportional to improvements in fuel efficiency (International Air Transport Association, 2011).

Aircraft engines are required to meet mandatory certification requirements which are established by the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection. The emission certification of aircraft engines, the limits of harmful substances and the specifications of metering devices are included in Annex 16, Part II of the 1944 Chicago *Convention on International Civil Aviation* (International Civil Aviation Organization, 2008; Kazda and Caves, 2015). The ICAO has adopted certification standards for NOx, CO, HC and smoke. At the time of the present study, certification requirement for non-volatile particulate matter is under development (International Air Transport Association, 2019).

3. Research method

3.1. Research approach

The research undertaken in this study was explanatory in nature (Creswell, 2014; Creswell, 2015; Cresswell and Cresswell, 2017; Yin, 2018) and used a mixed methods research design (Creswell, 2015; Cresswell and Plano-Clark, 2011; Leavy, 2017; Neale, 2018). The first phase of the study was a developmental design, specifically a quantitative longitudinal study utilizing correlation (and regression) to assess the statistical significance of any observed "growth, change, and development over time". The purpose for utilizing a longitudinal study is because attributes "usually develop, grow, and change in essential ways over a period of time" (Kalaian and Kasim, 2008). The second phased of the study used a qualitative longitudinal case study (Derrington, 2019; Neale, 2018). The goal of such an approach is to expand and develop theories rather than perform statistical analysis to test a certain hypothesis (Rahim and Baksh, 2003). As Yin (2009) notes that "a case study, whilst like an experiment, does not represent a sample, and the researcher's role is to expand and generalize theories (analytical generalization) and not to enumerate frequencies (statistical generalization)".

3.2. Data collection

The data for this study was obtained from a range of documents, including the Kansai International Airport Eco-Island Report 2007; New Kansai International Company Environmental 2014, 2015 and 2017 Environmental Reports, New Kansai International Company 2014 and 2015 Kansai International Smart Island Reports, and the 2016 Kansai International Airports Smart Island Report.

Qualitative data was also sourced from the Kansai Airports web sites, and air transport and airport industry-related magazines. The study therefore used secondary data analysis to investigate the research problem. The three principles of data collection as suggested by Yin (2018) were followed in this study: the use of multiple sources of case evidence, creation of a database on the subject, and the establishment of a chain of evidence.

3.3. Quantitative analysis

The research commenced with a developmental design to assess how Kansai International Airport, emissions, have developed from 2006 to 2016. That is, a quantitative longitudinal study utilizing correlation (and regression) was implemented to objectively assess the changes in emissions from Kansai International Airport from 2006 to 2016. In the longitudinal study, the statistical significance of the various year-on-year changes was quantitatively examined. This statistical analysis included the annual carbon dioxide (CO_2), methane, and nitrous oxides (N2O) emissions recorded at the airport over the period 2006 to 2016. To assess the significance of any trends, a Student t-test was utilized. The statistics tested the following hypotheses:

Null hypothesis (H0): $r = 0$
Alternative hypothesis (HA1): $r > 0$, or
Alternative hypothesis (HA2): $r < 0$

That is, the objective of the statistical test is to determine if the correlation coefficient, r, is essentially 0, and hence, there is no change over time, or alternatively 1) there is a positive trend overtime for a construct which is expected to increase, given by a positive correlation coefficient, or 2) there is a negative trend overtime for the construct which would be expected to decrease, given by a negative correlation coefficient. As such, only one-sided tests were utilized. The *t*-test used in the present study followed the standard as outlined by Heavey (2011) and Heiman (2011), which requires the calculation of the correlation coefficient and knowing the number of data points, n (twelve in the review period). Specifically

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}, \quad (1)$$

where the value (n – 2) is referred to as the number of degrees of freedom, α. This is then used to calculate a probability or a p-value. The p-value is then assessed relative to the level of statistical significance utilized. In this study, a statistical significance of 95% was utilized. This gives an alpha (α) of 0.05. If the p-value, which corresponds to the one-sided t-statistic and is greater than α, we accept the null hypothesis. That is, any observed trend is not considered statistically significant. If, however, the p-value is less than α, then we reject the null hypothesis as the trend is considered statistically significant.

3.4. Qualitative analysis

The goal of the second phase of this research was to understand what measures and strategies that had been implemented by Kansai International Airport to achieve any statistically significant results in their emission levels. That is, a case study of Kansai International Airport strategies for emissions reduction was used to explain the observed trends. The empirical data collected for the case studies was examined using document analysis. According to Altheide and Schneider (2013, p. 5), document analysis "refers to an integrated and conceptually informed method, procedure, and technique for locating, identifying, retrieving, and analyzing documents for their relevance, significance and meaning". Document analysis is often used in case studies and focuses on the information and data from formal documents and company records (Payne and Payne, 2004; Scott and Marshall, 2009). The documents collected for the present study were examined according to four criteria: authenticity, credibility, representativeness and meaning (Anderson, 2013; Fulcher and Scott, 2011).

Chester (2016) notes that authenticity refers to whether a document is genuine, complete, and reliable, as well as being of unquestioned authorship. A second criterion in appraising documentary materials is determining their credibility and identifying whether the document's information is both honest and accurate (He *et al*., 2015). Hence, credibility refers to the extent to which a document is sincere and not distorted and is free from error and evasion (Scott, 1990). A third criterion, representativeness, refers to the "general problem of assessing the typicality or otherwise of the evidence" (Scott, 1990) collected for the study. A final criterion—meaning—refers to the degree to which the evidence is clear and comprehensible to the researcher(s) (Baxter and Srisaeng, 2018b).

The documents gathered for the study covered the period from 2006 to 2016 All the gathered documents were downloaded and stored into a case study database (Yin, 2018). The documents collected for the study were all in English. Each document was carefully read, and key themes relevant to the study were coded and recorded (Baxter and Srisaeng, 2018a; van Schoor, 2017).

This study followed the recommendation of van Schoor (2017) who has suggested to avoid bias, documents of different sources should be analyzed. Triangulation is used to add discipline to a study in both qualitative and quantitative research. One of the primary reasons for the use of triangulation in a case study is the recognition that bias can be introduced if only one way of obtaining and interpreting data is used in the study. Triangulation is also used in qualitative research as a procedure to ensure stronger accuracy, and to demonstrate the verification of the data. This study used data triangulation by first relying on the factual quantitative data to establish those trends that were statistically significant, and then relying on qualitative data to established what strategies had been implemented with respect to these statistically significant results. That is, the potentially subjective reporting of initiatives and endeavours by Kansai International Airport which have not resulted in statistically significant changes over time have been excluded.

4. Results

4.1. A brief overview of Kansai International Airport

Kansai International Airport is in the southern region of the Osaka Bay which is in the Kansai Region of western Japan (Morikawa *et al*., 2007). The airport was constructed as a man-made island five kilometres offshore in Osaka Bay. The airport, which was estimated to have cost around $USD 14 billion (Landers, 2000), began operations in 1994 as Japan's first 24-hour airport. The airport now plays a very important role as an international hub in the global air transport network. As noted earlier, the airport is now Japan's third busiest airport. From its inception of operations, Kansai International Airport has sought to bring to reality the concept of a pollution-free airport, whilst at the same time existing and prospering together with the community (Kansai International Airport Company, 2012).

Kansai International Airport has been constructed in two discrete phases. In Phase 1, an airport island with a land area of approximately 510 hectares was reclaimed. A 3,500-metre-long runway and the related infrastructure were built on the island (Morikawa *et al*., 2007). During the early 1990s, the number of aircraft movements during the morning and early evening peak periods exceeded the airport's handling capacity of 30 aircraft movements per hour. Consequently, to accommodate demand and operate as an international hub airport, the second phase of the airport development began in 1999 (Baxter *et al*., 2018b). In the 2nd phase project a second man-made island 545 hectares in size was developed. The airport's second runway, which is 4,000 metre in length, was constructed on the second island (Dempsey, 2000; Furudoi, 2010). The airport officially opened its second runway in 2007 (Graham, 2018). The opening of the second runway provided the airport with the ability to become an international air transport hub.

The New Kansai International Airport Company (NKIAC) was established on April 1, 2012. The management of Kansai International Airport and Osaka International Airport (IATA Airport Code: ITM) was integrated into a single company on July 1, 2012 (New Kansai International Airport Company, 2014b).

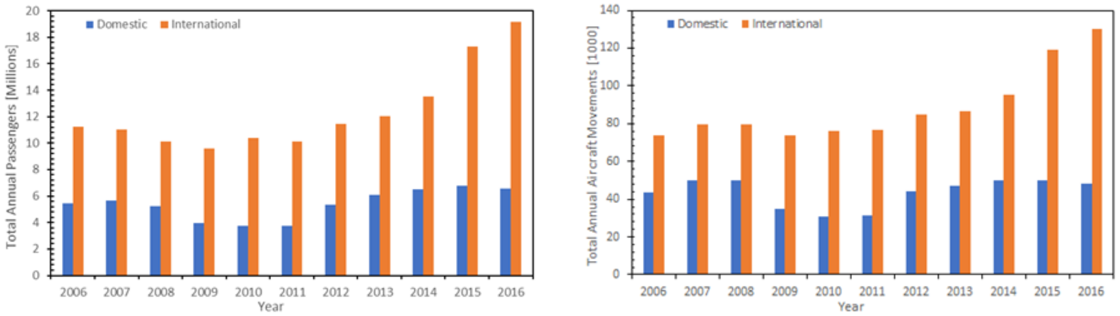
The Japanese government announced that it intended to sell the rights to operate the facilities at Kansai International Airport in June 2014. This decision arose as part of the government's debt reduction program (Airport Technology, 2014). This was Japan's first airport privatization deal (Airport World, 2014). In December 2016, a consortium that was led by the very large Japanese leasing firm Orix and Vinci Airports of France acquired the rights to operate the two Osaka-area airports (Osaka International Airport and Kansai International Airport). The contract commenced in April 2016. The contract to operate the two airports for a period of 44 years was valued at around ¥2.2 trillion yen ($USD18 billion). Thirty other firms have also invested in the venture. These firms include Kansai Electric Power, Hanshin Hankyu Holdings and Panasonic (Nikkei Asian Review, 2015).

Kansai International Airport's total annual domestic and international passengers for the period 2006 to 2016 are presented in Figure 1 (a). As can be observed in Figure 1 (a), international passengers constitute the largest source of passengers at Kansai International Airport. Since 2011, however, there has been strong growth in the number of domestic passengers handled at the airport. This is primarily due to the introduction of services by the low-cost carriers (LCCs), such as Jetstar Japan and Peach Aviation, Figure 1 (a). Kansai International is now the largest low-cost carrier hub in Japan. All Nippon Airways (ANA) and Japan Airlines are the two largest airlines serving the airport. Also, as can be observed in Figure 1 (a), the annual volumes of enplaned passengers declined in significantly in 2008 and 2009 due to the global financial crisis (GFC). Since 2010, both domestic and international enplaned passengers have grown strongly, Figure 1 (a) (Baxter *et al*., 2018a).

Figure 1 (b) shows Kansai International Airport's total annual domestic and international aircraft movements from 2006 to 2016. International flights account for the largest number of aircraft movements at Kansai International Airport, Figure 1 (b). The introduction of services by the LCCs in recent times, has contributed to the growth in domestic aircraft movements. As can be seen in Figure 1 (b), both domestic and international aircraft movements declined in 2009 and 2010 because of the effects of the global financial crisis (GFC). However, since 2011, both the total annual domestic and international aircraft movements have also grown strongly. The strong development from 2012 to 2016 in both domestic and international LCC services has contributed to the growth in aircraft movements at the airport, Figure 1 (b) (Baxter *et al*., 2018a).

4.2. Annual CO_2 emissions at Kansai International Airport

The total annual carbon dioxide (CO_2) emissions produced at Kansai International Airport for the period 2006 to 2016 and the year-on-year change (%) are presented in Figure 2. As can be observed in Figure 2 (a), the total annual CO_2 emissions declined significantly in 2008 and 2009 following the downturn in air travel demand because of the global financial crisis; this downturn impacted significantly aircraft movements at the airport. Since 2010, there has been a steady increase in CO_2 emissions following the growth in airline traffic (both passengers and cargo), and especially the increase in aircraft movements of the low-cost carriers (LCCs), who provide both domestic and international services from the airport. In addition to the growth in passenger aircraft movements, Kansai International Airport has also experienced an increase in the number of passenger airlines operating dedicated freighter aircraft. Dedicated all-cargo operators, and freighter services provided by the integrated carriers, for example, FedEx and United Parcel Services (UPS). On April 8, 2014, FedEx, one of the world's largest transportation companies, opened a hub its North Pacific Regional Hub at Kansai International Airport (FedEx, 2014). The FedEx hub is served by dedicated freighter aircraft.



(a) (b)

Figure 1. Annual traffic, domestic and international, for Kansai International Airport: (a) passenger numbers; (b) air transport movements (ATMs). Source: Data derived from Kansai Airports (2019)

The total annual carbon dioxide (CO_2) emissions produced from the aircraft serving Kansai International Airport from 2006 to 2016 and the year-on-year change (%) are presented in Figure 2 (b). Figure 2 (b) shows the impact of the global financial crisis of 2008 and 2009 on the downturn in aircraft movements, and thus, the level of CO_2 emissions from aircraft declined at Kansai International Airport due to the lower number of aircraft movements. Furthermore, in recent times the aircraft engine manufacturers, such as, General Electric and Rolls Royce Aerospace have endeavoured to reduce CO_2 emissions to meet prescribed targets. Consequently, modern aircraft engines are now considered more reliable and efficient (Whealan George *et al*., 2017). The airlines serving Kansai International Airport have introduced the latest start-of-the-art aircraft into their fleets, for example the Airbus A350-900XWB and Boeing 787 aircraft, which have made a positive contribution to the emissions reduction at the airport.

Figure 2 (c) presents the total annual carbon dioxide (CO_2) emissions and the year-on-year change (%) produced by the Kansai Airports Company, in its role as the airport operator. The sources of these emissions include the operation of company petrol- or diesel-powered vehicles, the airport's rubbish and wastewater treatment plants, and the vehicles used for landscaping and the washing of the airport's runways and roads.

The total annual carbon dioxide emissions (CO_2) produced from the businesses and operators providing services at Kansai International Airport and the year-on-year change (%) is depicted in Figure 2 (d). As can be observed in Figure 2a, CO_2 emissions declined significantly in 2009 and 2010, before increasing by 23 % in 2011. Over the period 2013-2016, the annual CO_2 emissions have remained relatively constant. This is despite the increase in both passengers (PAX) and aircraft movements (ATMs) over this period.

4.3. Other emissions at Kansai International Airport

Prior to examining the methane emissions at Kansai Airport, it is important to note that Kansai International Airport reports their methane emissions as a carbon dioxide equivalent (CO_2-eq). According to the Organization for Economic Cooperation and Development (2013), "carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential". The annual trend in methane emissions (carbon dioxide equivalent) at Kansai International

Airport: for the period 2006 to 2016 is presented in Figure 3 (a). Figure 3 (b) shows the total annual nitrous oxides (carbon dioxide equivalent) produced at Kansai International Airport for the period 2006 to 2016. The year-on-year trend for the methane emissions (Figure 3 shows all but 2 years of growth, and hence the overall trend of the methane emissions is increasing, with a significant jump from 2014 to 2015. In contrast, the nitrous oxide emissions (Figure 3 (b)) have been consistent, with 4 years of reduction, and 5 years of growth.

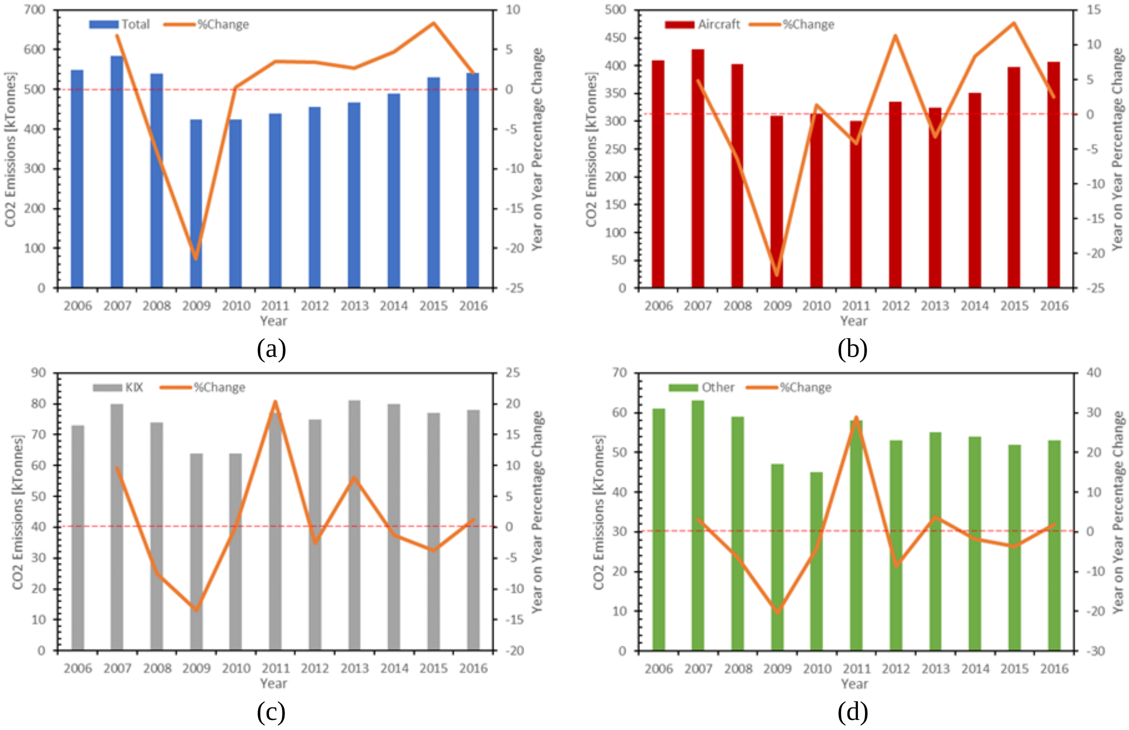


Figure 2. Annual carbon dioxide (CO_2) emissions for Kansai International Airport: (a) total amount from all sources; (b) from all aircraft operations; (c) from Kansai Airports Company; from all other on airport operators. Source: Data derived from New Kansai International Airport Company (2014b), Kansai International Airport (2017). Note: Emissions from aircraft are calculated to include the airport-related portion of the aircraft landing/takeoff (LTO) cycle as defined by ICAO, that is, the movement of the aircraft between an altitude of 3,000 feet and the ground for both landing and takeoff. The emissions from vehicles are from those vehicles operating with the airport's restricted zones, and excludes trains, ships, and vehicles travelling to and from the airport. The emission factors associated with emission factors for procured electricity are calculated from Kansai Electric Power Co. coefficients for each year

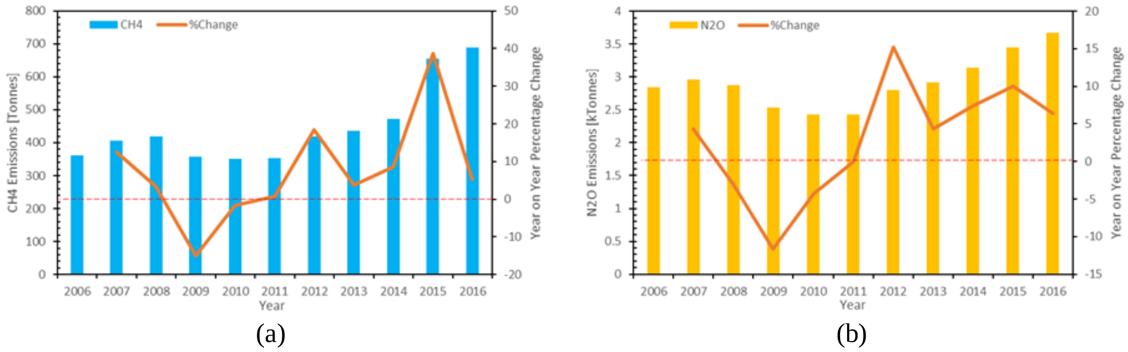


Figure 3. Other annual gaseous emissions for Kansai International Airport: (a) methane (CH4); (b) nitrous oxide (N2O). Source: Data derived from New Kansai International Airport Company (2014b), Kansai International Airport (2017)

4.4. Analysis

Summary data

Table 1 presents the results for the statistical testing from the regression analysis. Here, the emissions parameters (per passenger, PAX, and per aircraft movement (ATM) are statistically tested.

A one-tailed test was utilized, with a confidence level of 95%, and based on the 11-year data set this gives 9 degrees of freedom. Table 1 includes the correlation coefficients (*r*), the corresponding *t*-value, and the associated *p*-value based on the testing parameters, in addition to the direction of the observed trend (increasing, decreasing, or constant). The only insignificant result is for methane per passengers, which we conclude is constant (not changing over time). There is also only 1 metric that is increasing, and this is methane per aircraft movement. All other metrics show a statistically significant reduction over the period of the study.

Table 1. The correlation assessment of emission parameters for various metrics, all testing at the 95% confidence level, with 9 degrees of freedom (11 years), using a one-tailed test, where alpha = 0.05

Gas	Source	Metric	*r*	*t*	*P*	Trend
CO_2	Total	PAX	-0.949	-9.07	<0.001	Decreasing
		ATM	-0.971	-12.25	<0.001	Decreasing
	Aircraft	PAX	-0.966	-11.15	<0.001	Decreasing
		ATM	-0.978	-13.97	<0.001	Decreasing
	KIX	PAX	-0.671	-2.72	<0.001	Decreasing
		ATM	-0.631	-2.44	<0.001	Decreasing
	Other	PAX	-0.829	-4.45	<0.001	Decreasing
		ATM	-0.830	-4.46	<0.001	Decreasing
CH4	Total	PAX	0.363	1.17	<0.001	Constant
		ATM	0.777	3.70	<0.001	Increasing
N2O	Total	PAX	-0.834	-4.53	<0.001	Decreasing
		ATM	-0.898	-6.11	<0.001	Decreasing

Legend: ATM=Air transport movement; KIX = Kansai Airports Company; PAX= passengers

Annual CO_2 emissions

Figure 4 shows the annual carbon dioxide emissions (CO_2) per passenger, PAX, (blue circles) and per aircraft transport movement, ATM, (orange squares) at Kansai International Airport from 2006 to 2016. Figure 4 (a) is the total CO_2, Figure 4 (b) is CO_2 emissions from aircraft operations, Figure 4 (c) is the CO_2 emissions from Kansai Airport Company, and Figure 4 (d) is the CO_2 emissions from all other airport operators.

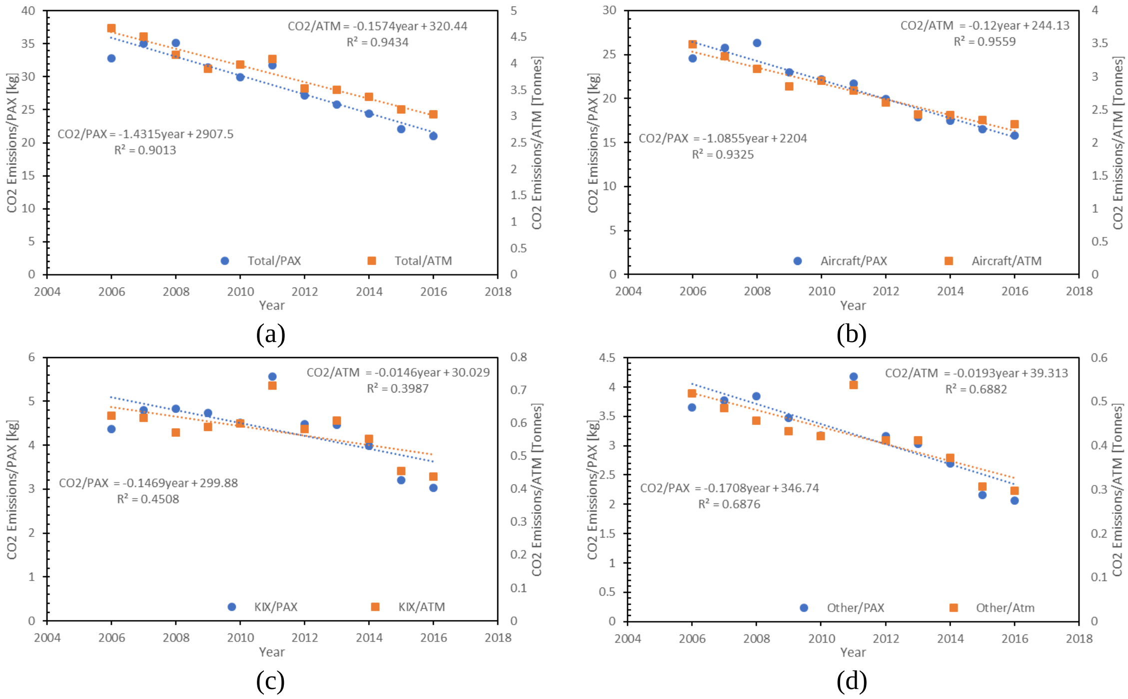


Figure 4. Annual carbon dioxide (CO2) emissions for Kansai International Airport per passenger carried (PAX), and per air transport movement (ATM): (a) total amount from all sources; (b) from all aircraft operations; (c) from Kansai Airports Company; (d) from all other on airport operators. Source: Data derived from New Kansai International Airport Company (2014b), Kansai International Airport (2017)

As shown in Table 1, each of the overlaid linear relationships is statistically significant, indicating that all these sources have decreased over the period of the study, for both metrics (per PAX and per ATM). Observation of the lines of best fit, suggest that the per ATM numbers have decreased more than the per PAX numbers, relatively speaking (the comparative gradients, side-by-side, of the blue lines are all steeper); this is likely due to the rate of growth in passenger numbers and the rate of growth in aircraft movements being different.

Other emissions

Figure 5 (a) shows the annual methane emissions (CH_4) per passenger, PAX, (blue circles) and per aircraft transport movement, ATM, (orange squares) at Kansai International Airport from 2006 to 2016. Figure 5 (b) shows the annual nitrous oxide emissions (N_2O) per passenger, PAX, (blue circles) and per aircraft transport movement, ATM, (orange squares) at Kansai International Airport from 2006 to 2016. As indicated with the results of Table 1, the overlaid linear relationships vary, in contrast to the CO_2 results. That is, the methane per passenger has remained consistent (with a slight increase apparent) over the period of the study. Based on the increased methane relative to the number of aircraft movements, the overall trend over the period of study for methane per ATM is increasing.

The most interesting trends are in Figure 5 (b), which show the significant reduction in nitrous oxides (NOx) for both metrics (per PAX and per ATM). This is interesting, because the compounding influence of making aircraft engines more fuel efficient, and hence, reducing CO_2 emissions, is an associated increase in nitrous oxide emissions; this results from new more efficient engines burning hotter, which then in the reaction process, indirectly produces nitrous oxides.

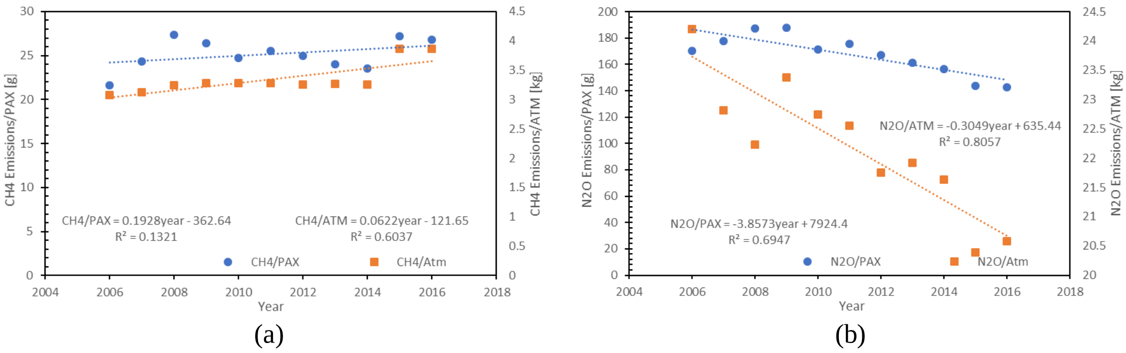


Figure 5. Other gaseous emissions annually for Kansai International Airport per passenger (PAX) carried, and per air transport movement (ATM): (a) methane (CH4); (b) nitrous oxide (N2O). Source: Data derived from New Kansai International Airport Company (2014b), Kansai International Airport (2017)

The reduction achieved in nitrous oxide levels (NOx), will be likely due to ground handling procedures evolving to reduce the need for aircraft to run their own engines for air and electricity (including the auxiliary power unit). Gate supplied air and power to aircraft are key strategies to helping reduce direct aircraft emissions, while aircraft are on the ground in between flights. These are discussed in more detail below.

The potential reasons for increased methane (CH3) gas emissions include natural gas fueled vehicles, additional aircraft where methane is greater at low thrust settings associated with airport movements, and additional waste and water processing and treatment the airport on site.

Initiatives to reduce emissions at Kansai International Airport

Over the years, Kansai International Airport has placed a very significant focus on the mitigation of emissions and has implemented a range of measures whose objective are to reduce the environmental impact of emissions.

As noted earlier, air pollution at an airport is not only produced by aircraft during the landing and take-off (LTO) cycle but also from the ground service equipment (GSE) used during airport ground handling operations (Testa *et al.*, 2014). Thus, in addition to the carbon dioxide (CO2) emissions generated by aircraft, aircraft ground operations carbon dioxide (CO2) emissions can also be significant at airports (International Airport Review, 2010). The replacement of internal combustion engine powered airport ground support vehicles and equipment can potentially reduce carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), and particulate matter (PM) (Gellings, 2011). In recent years, Kansai International Airport has been gradually introducing "eco-cars" (electric, fuel cell, natural gas, hybrid, plug-in hybrid, and ultra-fuel-efficient vehicles) when vehicles require replacement. The Airport

Authority has also been encouraging contractors to convert their fleets to low-emission vehicles (New Kansai International Airport Company Ltd, 2015a). In August 2006, Kansai International Airport and Rinku Town were selected as a region for the dissemination and promotion of the use of compressed natural gas (CNG) powered vehicles (Kansai International Airport Company Ltd, 2007).

Accordingly, another important sustainable environment strategy implemented by Kansai International Airport has been a policy to gradually introduce "eco-cars" (electric, fuel cell, natural gas, hybrid, plug-in hybrid, and ultra-fuel-efficient vehicles) when vehicles are being replaced or when other opportunities arise. The Kansai International Airport Taxi Operators Council has also been introducing eco-friendly vehicles (New Kansai International Airport Company Ltd, 2014b). Electric-powered cars also offer their operators several important environmental benefits: a reduction in noise and pollution, and they also help to reduce the reliance of transport modes on oil – providing, of course, that the power is produced from fuels other than oil. Importantly, electric-powered vehicles can also be used to reduce carbon emissions (Larminie and Lowry, 2012). In March 2017, there were 402 low emissions "Eco-cars" (vehicles) authorized to operate inside the airport's restricted areas, of these, 191 were electric-powered vehicles (Kansai International Airport Company Ltd, 2017).

In addition, a variety of handling activities are undertaken at airports (Ashford *et al*., 2013; Kazda and Caves, 2015). Consequently, electrical power is required on the airport apron for the servicing of aircraft prior to engine start-up. (Horonjeff *et al*., 2010). To reduce emissions of CO2 and air pollutants from the use of aircraft auxiliary power units (APUs), Kansai International Airport has installed fixed electrical ground power units (FEGPs) at aircraft parking spots to provide electricity and air conditioning. The airport requests airlines to use this system. In January 2010, Kansai International Airport became the first Japan-based airport to reduce the amount of time an aircraft can use its auxiliary power unit (APU) prior to its scheduled departure; the time was reduced to 15 minutes from the previous 30 minutes (New Kansai International Airport Company Ltd, 2014a). Figure 6 presents the percentage uptake in FEGP usage amongst the airlines providing services to and from the airport and the corresponding year-on-year changes (%) at Kansai International Airport from 2002-2017. As can be seen in Figure 6, the percentage of international airlines operating at the airport and utilizing FEGP have, following a relatively slow start, increased the adoption of the system, specifically since 2009 (Baxter *et al*., 2018b).

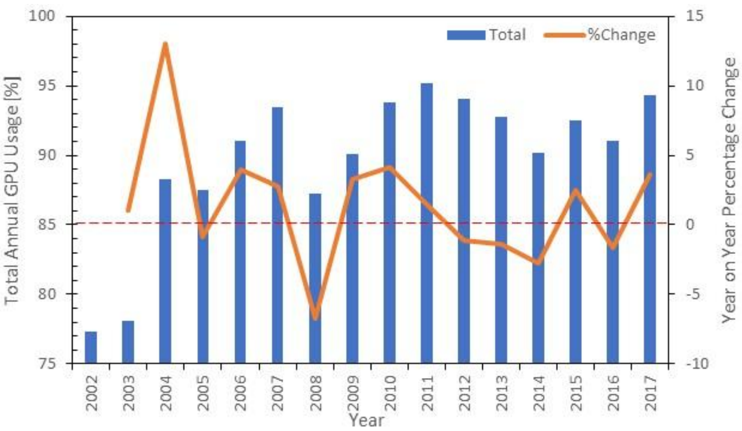


Figure 6. Total annual ground power unit system usage by all airlines and year-on-year change (%): 2002-2017. Source: data derived from Kansai International Airport Company (2013, 2017), Kansai Airports (2018)

Kansai International Airport is also actively pursuing the use of clean energy sources as part of its commitment to sustainable airport operations. This objective is guided by the airport's Smart Island Vision. In May 2014, the airport decided to proceed with the full-scale launch of the airport's Hydrogen Grid Project. This is an important element of the airport's Smart Island Vision. The airport's Hydrogen Grid Project received the support of Japan's national government and made use of its "Comprehensive Special Zones for International Competitiveness Development program" (New Kansai International Airport Company, 2015b). Kansai International Airport's Hydrogen Grid Project was the first in Japan to demonstrate the large-scale introduction and use of hydrogen energy at the airport's facilities (New Kansai International Airport Company, 2014b). Kansai International Airport was the first Asia-based airport to introduce the use of hydrogen powered forklifts. The use of these forklifts will result in a reduction of emissions of CO2, as well as providing an improvement in working efficiency (New Kansai International Airport Company, 2015a). In March 2016, All Nippon Airways and the Japan Airlines

Groups commenced the use of two fuel-cell hydrogen powered forklifts. The forklifts use the same type of fuel cell as the hydrogen powered Toyota Mirai cars that operates at the airport (Kansai Airports, 2016). It is most important to note, however, that the production of hydrogen from non-renewable feedstock (coal, natural gas, and oil), however, causes the production of carbon dioxide (CO2) gases (Balachandar *et al.*, 2016; Dincer and Joshi, 2013) which are detrimental to the environment. In contrast, hydrogen produced using renewable sources would not create greenhouse emissions or, in the case where biomass is used as the feedstock, then this would create near zero emissions (Yeang and Woo, 2010). It is important for airports to consider sourcing hydrogen produced from renewable energy sources to ensure the least environment impact of using this energy source (Baxter *et al.*, 2018b).

The ground support equipment (GSE) used to service aircraft whilst they are on the ground in between flights are the predominant emitters of carbon monoxide (CO) at airports. Traditional fossil fuel powered GSE equipment also emit hydrocarbons (HC), nitrous oxide (NOX), sulphur oxide (SOX), and particulate matter (PM). To mitigate these adverse environmental affects, the replacement of internal combustion powered GSE with electric-powered vehicles can potentially reduce CO, NOX and HC, but may slightly increase SOX emissions (Gellings, 2011). One of the major ground handling agents operating at Kansai International Airport, CKTS Company Ltd, has introduced electric powered carts for bulk loaded passenger baggage (KTS Company Ltd, 2020). To further reduce their GSE emissions further, the major ground handling agents operating at Kansai International Airport could consider the use of electric powered push bag tugs (Baxter *et al.*, 2015), as well as electric powered water serving and lavatory trucks, and so forth.

As a business organization that is prescribed under Japan's Nitrogen Oxides and Particulate Matter Act, the airport is required to prepare a vehicle-use management plan to reduce emissions of nitrogen oxides (NOx) and particulate matter (PM) (New Kansai Airport Company Ltd, 2015a). To reduce vehicle idling times at the airport, signs and posters are displayed in parking lots and other public places at Kansai International Airport. The airport's Smart Island Council also conducts a vehicle idling-prevention awareness campaign targeted at drivers and passengers at the airport during the annual International Environment Month (each June) (New Kansai Airport Company Ltd, 2014a).

Other initiatives implemented at Kansai International Airport to reduce emissions include the efficient operation of the passenger terminal air conditioning system using information technology (IT), which provides a reduction in carbon dioxide (CO2) emissions of around 1,500 tonnes per annum; installation of photovoltaic systems, for example, the "KIX Megasolar" system, and a wind-powered system that is located in the airport's Sora Park (Baxter *et al*., 2018b).

5. Conclusions

This study has examined, for the first time, the aircraft and airport-related emissions produced at Osaka's Kansai International Airport from 2006 to 2016. The study used a mixed methods research approach. The data collected for the study was examined using document analysis. The qualitative case study was underpinned by the research framework that followed the guidelines recommended by Yin (2018). The study found that the strategies implemented to reduce the airports gaseous emission have resulted in statistically significant reduction for carbon dioxide (CO_2), from all airport sources, measured relative to both passengers and aircraft numbers utilizing the airport. That is, while carbon dioxide (CO_2) emissions have remained fairly constant over the period of the study (no statistically significant change), the number of passengers and aircraft served by the airport has increased.

The operation of modern next generation aircraft, such as the Airbus A350-900XWB and the Boeing 787-8/-9 aircraft, have made a positive contribution to the airport's efforts to mitigate its emissions. Kansai International Airport has also been able to reduce its emissions through a range of environmental-related initiatives, including the introduction of hydrogen powered handling equipment, the introduction of electric-powered baggage carts, the application of IT systems to more efficiently operate passenger terminal air conditioning systems, as well as the wide spread use of photo-voltaic solar powered systems.

Future work could be undertaken to further investigate specific sources of emissions in each of the three areas (airport company, aircraft, and other), to implement strategies with maximal impact. Ideally on-site monitoring could be implemented to look at geospatial and temporal distributions of emission. Furthermore, as a significant cargo airport, it would be worth looking at the individual air cargo terminals (conventional and integrated carrier) to be able to compare and contrast the emissions of each of these different airport facilities.

In general, no specific recommendations need to be made, the work being undertaken by the Kansai Airport Company, is resulting in significant reductions in carbon dioxide emissions. It will be interesting to further monitor the methane emissions, to determine if this is a new steady state, or if this will continue to increase, or if measures should be put in place to try to reduce these emissions.

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