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ACHIEVING CARBON NEUTRAL AIRPORT OPERATIONS BY 2025: THE CASE OF SYDNEY AIRPORT, AUSTRALIA

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Using a qualitative instrumental case study research design, this study examines the strategies and carbon reduction measures implemented by Sydney Airport to achieve their goal of being a carbon neutral airport by 2025. The study period was from 2013 to 2019. The qualitative data was analyzed using document analysis. Sydney Airport has implemented a wide range of carbon reduction measures that underpin its strategy to become a carbon neutral airport. Sydney Airport's annual emissions intensity per passenger declined in each year examined in study. Sydney Airport has participated in the Airports Council International Airport Carbon Accreditation Program since 2014 and currently holds Accreditation Level 3: Optimization. Sydney Airport's goal is to be awarded Accreditation Level 3+: Carbon Neutrality by 2025. Sydney Airport has a carbon offsets agreement in place with a not-for-profit organization.

Keywords: Airport, Airport Carbon Accreditation Program, Carbon Emissions, Carbon neutrality, Carbon Offsets, Sydney Airport

1. Introduction

Airports located throughout the world are increasingly focusing on their environmental impact, and, as a result, have increased their efforts in reducing air transport impacts by applying environmental management, certification systems, or other forms of ecological rating systems to their infrastructures and operation (Comendador *et al.*, 2019). Airports are indeed impacted by climate change and just like other industry sectors around the world, airports must provide measures to combat climate change. Airports are regarded as nationally critical infrastructure as they facilitate both mobility and economic growth. However, due to their fixed infrastructure, for example, runways and terminal buildings, and vulnerability to disruptive weather, they are predominantly at risk from the potential consequences of climate change. These impacts include sea levels rising, higher temperatures and greater weather extremes creating both an operational and business risk for airports (Njeri Gitau, 2019). Other potential impacts include airport infrastructure being subject to extreme heat and cold, shifting tourism and travel preferences as well as regulatory programs that internalize the cost of carbon dioxide (CO₂) and other greenhouse gases (GHGs) with taxes and fees (Preston, 2015).

In recent times, there has been a growing trend towards airports becoming “carbon neutral” (Allett, 2008; Boussauw and Vanoutrive, 2019; Falk and Hagsten, 2020; Graham, 2018). Carbon neutral airports aim to attain net zero greenhouse gas emissions (GHGs) by balancing the level of carbon emitted at the airport with an equivalent amount sequestered or offset. Airports achieve this through obtaining offset credits that are equal to the number of metric tonnes emitted via a certain greenhouse gas (GHG) emitting activity (Ritter *et al.*, 2011).

One such airport that has defined and implemented a plan to become a carbon neutral airport by 2025 is Sydney Airport. Sydney Airport was thus selected as the case airport for the present study. A further factor in selecting Sydney Airport as the case airport was the ready availability of data for the period 2013 to 2019. The objective of the study is to examine the strategies and measures that have been implemented by Sydney Airport to achieve their carbon neutral goal by 2025. A second objective is to examine how Sydney Airport's participation in the Airports Council International “Airport Carbon Accreditation Program” is underpinning the airport's objective of becoming carbon neutral by 2025. A third objective of the study was to examine the annual trend in the emissions intensity per enplaned passenger and to identify how this has changed overtime given the growth in Sydney Airport's total annual enplaned passengers during the study period. A final objective is to examine Sydney Airport's annual carbon offsets strategy.

The remainder of the paper is organized as follows: the literature review is presented in Section 2 and this sets the context of the case study. The research method that underpinned the study follows in Section 3. The Sydney Airport case study is presented in Section 4. Section 5 presents the key findings of the study.

2. Background

2.1. Air quality at airports

The growth of commercial air transport has driven concerns over air quality around airports and their surrounding communities (Lobo *et al.*, 2012). By consuming fuel, aircraft produce emissions of carbon dioxide (CO₂), nitrogen oxides (NO_x), particles (principally soot) of sulphur oxides, carbon monoxide (CO), as well as various hydrocarbons. After water vapour, carbon dioxide (CO₂) is regarded as the second most important of all the greenhouse gases (Ngo and Natowitz, 2016). These can involve broader environmental issues related to ground level ozone (O₃), acid rain and climate change, and present potential risks relating to public health and the environment. Furthermore, aircraft often travel considerable distances at a variety of altitudes, generating emissions that may potentially have an impact on air quality in not only local, but also regional and global environments (International Civil Aviation Organization, 2011).

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 spends 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, p. 714).

Pollutants are also produced during aircraft taxiing, at take-off, at landing, and often during the period they are idle. Surface vehicles associated with the transportation of crews and their baggage, are a second source of air pollutants. Ground service equipment (GSE) are also a source of air pollutants. The fourth pollution source is the generation of power to produce electricity, and heating and cooling. The final source is the collection of landside commuter traffic generated by passengers, meeters and greeters, airport-related employees, and businesses (Prosperi, 2009). Accordingly, a critical concern of modern airports is the air pollution generated by air transport operations and its subsequent impact on the airport environment (Miroslavljević *et al.*, 2011).

2.2. Airport carbon accreditation programme

In the global air transport industry, several organisations and programmes have been developed to assist airports in reducing their carbon emissions. Such programs support airports to establish systems to identify, monitor and reduce sources of air pollution (Vanker *et al.*, 2013). The Airports Council International, the peak global airport body, Airport Carbon Accreditation Programme is an independent programme which enforces accreditation criteria for airports on an annual basis (Ritter *et al.*, 2011). The objective of this program is to assist airports to reduce their carbon footprint and ultimately move it to a zero value (Benito and Alonso, 2018). A further objective of the program is to push and enable airports to implement carbon and energy management best practices, whilst at the same time gaining public recognition for their achievements (Postorino *et al.*, 2017).

There are four stages for an airport achieving full carbon accreditation (Table 1).

Table 1. Airport Carbon Accreditation Program stages and requirements

Stage description	Requirements
Stage 1: Mapping	Airports should determine emissions sources within the operational boundary of the airport. Airport should calculate the annual carbon emissions. Airports should compile a carbon footprint report. Airport should engage an independent third-party to verify the carbon footprint report.
Stage 2: Reduction	Airports should have completed all of the Stage 1 requirements plus: Airports need to provide evidence of effective carbon management procedures and also show that reduction targets have been achieved.
Stage 3: Optimization	Airports should have satisfied the Stage 1 and 2 requirements plus: Airports need to widen the scope of their carbon footprint to include third party emissions. Airports should also engage third parties at and around the airport.
Stage 3+: Neutrality	Airports should have satisfied all the requirements associated with Stage 1 to 3 plus: Airports should offset their remaining emissions to achieve carbon neutral operations for all emissions over which the airport has control

Source: Airports Council International – Europe (2009).

The Airport Carbon Accreditation Programme is based on the internationally recognised “Greenhouse Gas Protocol” and has been implemented in all regions of the world (Preston, 2015).

2.3. Airport carbon footprint

Carbon footprint is becoming a widely used measure of assessing a firm's contribution to climate change (De Grosbois and Fennel, 2011). The carbon footprint is a measure of the impact of the activities of a firm has on the environment and on climate change. The carbon footprint is a calculation of all the firm's greenhouse gases that are produced, and these emissions are measured in tonnes or kilograms of carbon dioxide (CO₂) (Legrand *et al.*, 2017). It is important to note that a firm's carbon footprint is an exclusive measure of the carbon dioxide (CO₂) emissions that are both directly and indirectly caused by an activity (Wiedmann and Minx, 2007).

Despite differences in the air quality regulations between countries, airport operators are increasingly recording and publishing their Scope 1, 2 or 3 emissions (Budd, 2017). Scope 1 emissions come from sources that are owned and directly controlled by the airport. The Scope 1 emissions at an airport are produced by fuel-powered vehicles owned and operated by the airport, together with stationery sources, for example, heating systems or generators that burn fuel to service the airport. Scope 2 indirect emissions are those generated from the purchase of electricity to power airport facilities. Scope 3 emissions are a consequence of the activities that are performed at an airport. The emissions come from sources that are owned and operated by another party (Kim *et al.*, 2009).

2.4. Sustainable airport energy management

Electrical energy is required at airports for powering the aids to air transport operations, and for airport buildings, aircraft hangers and other airport facilities (Kazda *et al.*, 2015). Airports are also acknowledged as being extremely energy-intensive areas (Baxter *et al.*, 2018a; de Rubeis *et al.*, 2016). The large energy usage is due to the large buildings, for example, passenger terminal buildings, which are equipped with heating and air-conditioning systems. Also, there is a very high-power demand for lighting and electric equipment, and for the various facilities that are located within the airport precinct (Cardona *et al.*, 2006; Ortega Alba & Manana, 2017). An airport's heating, ventilation, and air conditioning (HVAC) system normally consumes the largest share of energy in airport terminal buildings (Akyüz *et al.*, 2017). Airports require a guaranteed, appropriately priced, and secure energy supply in order to satisfy peak demand from their stakeholders and passengers (Thomas and Hooper, 2013).

Diesel and gasolines are typically used to power the ground vehicles that are operated in an airport's airside and landside precincts. Electrical energy is normally sourced from various sources and is supplied directly to the airport through dedicated sub-stations (Janić, 2011).

There are some new energy technologies that are currently being developed as energy sources for airports. These include solar photovoltaic, concentrating solar power, wind power, oil and natural gas extraction, and steam-generated power production (Barrett *et al.*, 2014). The use of renewable energy sources contributes to a reduction of carbon dioxide (CO₂) emissions into the atmosphere (Dahmen *et al.*, 2008).

3. Research methodology

3.1. Research approach

This study used a qualitative instrumental case study research approach (Baxter, 2019; Johnson and Jones, 2018; Pedersen *et al.*, 2018). An instrumental case study is the study of a case, for instance, a firm, that provides insights into a specific issue, redraws generalizations, or builds theory (Stake, 1995, 2005). The instrumental case study research approach facilitates the understanding of a specific phenomenon and is designed around established theory (Grandy, 2010). The present study was designed around the established theory of carbon neutrality (Boussauw and Vanoutrive, 2019; Rauland and Newman, 2015; Zhou, 2020) and sustainable airport energy management (Baxter *et al.*, 2018a, 2018b).

3.2. Data collection

Data for the study was obtained from a range of documents: Sydney Airport Limited annual sustainability reports, Sydney Airport Limited annual reports, and Sydney Airport Limited materials available on the internet. These documents provided the sources of the study's case evidence. An exhaustive source of the leading air transport and airport-related journals and magazines was also conducted. The study also included a search of the SCOPUS and Google Scholar databases.

The key words used in the database searches included "Sydney Airport's environmental management policy", "Sydney Airport's environmental regulatory framework", "Sydney Airport's participation in the Airport Carbon Accreditation Program", "Sydney Airport's total carbon emissions", "Sydney Airport's total annual Scope 1, Scope 2, Scope 3 emissions", "Sydney Airport's annual emissions intensity per passenger", "Sydney Airport's total annual carbon offsets", and "Sydney Airport's carbon reduction initiatives".

Secondary data was therefore used in the study. The three principles of data collection as recommended by Skinner et al. (2015) and Yin (2018) were followed: 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. Data analysis

The empirical data collected for the case study was examined using document analysis. Case study researchers regularly use document analysis in their case studies. Document analysis focuses on the information and data from formal documents and company records gathered for a study (Oates, 2006; Ramon Gil-Garcia, 2012). The documents collected for the present study were examined according to four criteria: authenticity, credibility, representativeness and meaning (Fulcher and Scott, 2011; Scott and Marshall, 2009). Prior to beginning the formal analysis of the documents, the context in which the documents were created was determined and the authenticity of the documents was reviewed (Love, 2003). Authenticity involves an assessment of the collected documents for their soundness and authorship. Authorship relates to such issues as collective or institutional authorship. In this study the source of the case study documents was Sydney Airport Limited. The credibility criterion concerns the accuracy and sincerity of a document. The representativeness criterion involved an assessment of the availability and survival of the documents gathered. The fourth criterion, meaning, occurs at two levels in document analysis. The first is the literal understanding of a document, by which is meant its physical readability, the language used and whether it can be read, as well as the date of the document (Scott and Marshall, 2009).

The document analysis was undertaken in six distinct stages:

- Phase 1: The first phase involved planning the types and required documentation and their availability for the study.
- Phase 2: The data collection phase involved sourcing the documents and developing and implementing a scheme for the document management.
- Phase 3: The collected Documents were examined to assess their authenticity, credibility and to identify any potential bias.
- Phase 4: The content of the collected documents was carefully examined, and the key themes and issues were identified.
- Phase 5: This phase involved the deliberation and refinement to identify any difficulties associated with the documents, reviewing sources, as well as exploring the documents content.
- Phase 6: In this phase the analysis of the data was completed (O’Leary, 2004, p. 179).

Following the recommendation of Yin (2018), all the collected documents were downloaded and stored in a case study database. All the documents gathered for the study were all written in English. Each document was carefully read, and key themes were coded and recorded. The case study design and analysis were underpinned by a case study research framework (Baxter, 2019).

4. Results

4.1. A brief overview of Sydney Airport

Sydney Airport is in the suburb of Mascot, around 8 kilometres south of Sydney’s central business district. Sydney Airport is Australia’s busiest airport. In 2019, the airport handled a total of 44.4 million passengers. The origins of Sydney Airport can be traced back to 1919, when the Australian Aircraft and Engineering Company leased land from the Kensington Racing Club. An aerodrome was subsequently opened. By the mid-1920s, the airport was handling regular public transport services between Sydney, Melbourne, and Adelaide. A new passenger terminal was opened in the 1940s and the adjacent Cooks River was diverted so that two new runways could be constructed (Sydney Airport Limited, 2020d).

In 1965, work began on the construction of the airport’s north-south runway southwards into Botany Bay. During 1965, works commenced on the construction of the airport’s International Terminal Building. In 1994, the airport’s parallel runway was completed (Sydney Airport Limited, 2020d). The airport was privatized by the Australian Government in 2002 (Bowyer and Chapman, 2003; Neto *et al.*, 2016). At the time of the present study, the airport was owned by the Australian Stock Exchange (ASX) listed Sydney Airport Group (Sydney Airport Limited, 2020b).

The airport has three terminal buildings: T1 International, T2 Domestic (Jetstar Airways, Regional Express, Tigerair, and Virgin Australia) and T3 Domestic (Qantas Airways domestic flights; Qantaslink regional flights). The airport has seven air cargo terminals, which are controlled by five cargo terminal operators (Sydney Airport Limited, 2020d).

The main north-south runway is 3,962 metres in length, the parallel runway is 2,438 metres in length, and the east-west runway is 2,530 metres in length. The airport accommodates services by a full range of aircraft types, including the Airbus A380 aircraft (Sydney Airport Limited, 2020d).

Sydney Airport has developed and maintains an environmental management system (EMS). Sydney Airport's EMS is required by clause 5.02B of the Commonwealth *Airports Regulations 1997*. The airport's EMS follows the relevant Australian and international standards, that is, AS/NZS ISO14001:2015 Environmental Management Systems – Requirements with guidance for use (Sydney Airport Limited, 2019c).

Figure 1 presents the total annual enplaned passengers (domestic and international) handled by Sydney Airport and the year-on-year change (%) for the period 2013 to 2019. As can be observed in Figure 1, the total annual enplaned passengers increased from 37.8 million in 2013 to 44.4 million in 2019. The highest annual growth occurred in 2016, when the total annual enplaned passengers increased by 5.55% on the previous year levels (Figure 1).

Figure 1. Sydney Airport's total annual enplaned passengers and year-on-year change (%): 2013-2019
Source: Sydney Airport Limited (2015a, 2016a, 2017a, 2018a, 2019a, 2020a)

4.2. Sydney Airport energy savings and carbon reduction plan

In 2008, Sydney Airport became a signatory to the “Global Aviation Industry Commitment to Action on Climate Change”. This agreement was an important demonstration of the global air transport industry's voluntary commitment to researching and introducing technological, operational and efficiency advances that will reduce the industry's contribution to climate change and reduce its impact on the environment (Sydney Airport Limited, 2020c).

In 2017, Sydney Airport updated its “Energy Savings and Carbon Reduction Plan”, and in so doing identified new energy saving, greenhouse gas emission reduction and energy efficiency opportunities. Furthermore, the airport has set a new target which is to achieve a 50% reduction in emissions per passenger by 2025. As electricity and natural gas consumption are the major sources of carbon emissions at the airport, they are a major focus in the airport's “Energy Savings and Carbon Reduction Plan”. In addition, Sydney Airport plans to continue to develop and research further sustainable, cost effective energy initiatives, including the use of renewable energy such as solar power photovoltaic systems (Sydney Airport Limited, 2019c).

At the time of the study, the airport had committed to a target of being carbon neutral by 2025 (Sydney Airport Limited, 2018b, 2019b). This objective will be achieved through the Airport Carbon Accreditation (ACA) certification scheme.

4.3. Sydney Airport participation in the Airport Carbon Accreditation Program

On May 27, 2014, Sydney Airport was awarded the Airport Carbon Accreditation Level 1: Mapping certification. This required the mapping of the various sources of carbon dioxide (CO₂) emissions on the Sydney Airport site. The airport's carbon footprint was independently verified. Sydney Airport was also required to provide details of its greenhouse gas management (Sydney Airport Limited, 2015b).

During 2015, Sydney Airport achieved ACA Level Two Accreditation, which involved the development of an energy and carbon management plan for the company and establishing a target to reduce per passenger carbon emissions by 25% by 2020 (Sydney Airport Limited, 2016b).

Sydney Airport achieved ACA Level 3 accreditation in 2016 (Sydney Airport Limited, 2017b). At the time of the current study, Sydney Airport held Level 3 ‘Optimisation’ certification. This status was achieved in 2016. The ACA Level 3: Optimization requires airports to calculate Scope 1, 2 and 3 emissions as well as implement initiatives to reduce them (Sydney Airport Limited, 2020c).

4.4. Sydney Airport annual carbon emissions

Figure 2 presents Sydney Airport's total annual carbon emissions (tCO₂e) from 2013 to 2019. During this period, Sydney Airport was able to reduce its total annual carbon emissions from a high of 90,716 tCO₂e in 2013 to 83,620 tCO₂e in 2019 (Figure 2). As discussed below, Sydney Airport has implemented a wide range of energy management and carbon reduction measures that have played a key role in reducing the airport's annual carbon emissions over this period. This is demonstrated by the year-on-year percentage change line graph, which is more negative than positive, that is, more values are below the line than above. Indeed, Figure 2 shows that there was only one increase in Sydney Airport's annual carbon emissions which occurred in 2016, when the total carbon emissions increased by 2.62% on the previous year levels. This trend is also very favourable given the growth in both enplaned passengers and aircraft movements recorded at Sydney Airport over the study period.

Figure 2. Sydney Airport's total annual carbon emissions (tCO₂e) and year-on-year change (%): 2013-2019
Note: GHG inventory is compiled using Australia's National Greenhouse and Energy Reporting and the National Greenhouse Accounts Factors' methodologies. Source: Sydney Airport Limited (2016b, 2020e)

Figure 3 presents the annual trend in Sydney Airport's total Scope 1 emissions (tCO₂e) for the period 2013 to 2019. As can be observed in Figure 3, Sydney Airport's annual Scope 1 emissions have oscillated over the study period. The largest decline in the airport's total Scope 1 emissions occurred in 2014, when they decreased by 6.33% on the previous year levels (Figure 3). A second decline was recorded in 2018, when the Scope 1 levels decreased by 4.41% on the 2017 levels. There was a steady increase in the Scope 1 levels from 2014 to 2016 reflecting the airport's equipment increased usage patterns. The largest increase in Scope 1 emissions occurred in 2017, with the second highest increase occurring in 2015. The 2019 Scope 1 emissions increased by 3.33% on the 2018 levels (Figure 3).

Figure 3. Sydney Airport's total annual Scope 1 emissions (tCO₂e) and year-on-year change (%): 2013-2019 Note: Scope 1 emissions include CO₂, CH₄, and N₂O. Excludes biogenic CO₂ emissions Source: Sydney Airport Limited (2016b, 2020d)

Prior to examining Sydney Airport's Scope 2 emissions, it is important to note that the airport uses a significant amount of energy to operate its facilities, with almost 80% of the airport's energy use arising

from the purchase of electricity for heating, ventilation and cooling (HVAC) systems, lighting, baggage handling, passenger and goods lifts and elevators (Sydney Airport Limited, 2016b, 2018b). Figure 4 presents the annual trend in Sydney Airport's total Scope 2 emissions (tCO₂e) from 2013 to 2019. As can be seen in Figure 4, Sydney Airport's annual Scope 2 emissions peaked in 2013 and 2014 and then decreased in 2015 and 2016. There was an increase of 2.7% in Scope 2 emissions in 2017 and during 2018 and 2019 there were decreases of 0.87% and 4.28%, respectively (Figure 4). Despite the increase in passengers and aircraft movements, Sydney Airport has been largely able to reduce its Scope 2 emissions, which is illustrated by the year-on-year percentage change line graph being more negative.

Figure 4. Sydney Airport's total annual Scope 2 emissions (tCO₂e) and year-on-year change (%): 2013-2019 Note: Scope 2 emissions include CO₂ emissions. Source: Sydney Airport Limited (2016b, 2020e)

Scope 3 emissions are produced from activities that are central to Sydney Airport's operations and that the airport can guide and influence, but which are outside of the airport's direct control. Sydney Airport's Scope 3 emissions are reported in accordance with the Airport Council International's Airport Carbon Accreditation (ACA) program. The Scope 3 emissions are primarily made up of aircraft landing and take-off cycles (up to 1,000 metres elevation), and passenger, greeter/fareweller and staff travel to and from the airport (that is, surface access) (Sydney Airport Limited, 2020e). Figure 5 presents the annual trends in Sydney Airport's total Scope 3 emissions (tCO₂e) for the period 2016 to 2019. Figure 5 shows that there was a significant increase (17.65%) in Sydney Airport's Scope 3 emissions in 2017 on the 2016 levels. However, this was followed by a reduction of 21.08% in 2018, and a further small reduction of 0.07% in 2019 (Figure 5). The decline of 21.08% in 2018 is noteworthy, as the airport experienced a growth in enplaned passengers of 2.54%, yet the airport was still able to decrease its Scope 3 emissions.

Figure 5. Sydney Airport's total annual Scope 3 emissions (tCO₂e) and year-on-year change (%): 2016-2019. Note: data not available prior to 2016 Source: Sydney Airport Limited (2020e)

4.5. Sydney Airport total annual emissions intensity per enplaned passenger

Figure 6 presents the annual trends in total emissions intensity per enplaned passenger (kgCO₂e) at Sydney Airport for the period 2013 to 2019. As can be observed in Figure 6, the total annual emissions intensity per enplaned passenger (kgCO₂e) has declined each year during the study period from a high of 3.2 (kgCO₂e) in 2013 to 2.4 (kgCO₂e) in 2019. Figure 6 shows the largest single annual decrease occurred in 2016 when the total annual emissions intensity per enplaned passenger (kgCO₂e) declined by 10% on the previous year levels (Figure 6). The consistent annual decline in total annual emissions intensity per enplaned passenger (kgCO₂e) is very favourable for Sydney Airport, as this is one of an airport's key environmental-related metrics.

Sydney Airport's annual emissions intensity per passenger metric includes the airport's Scope 1 (CO₂, CH₄, and N₂O) and Scope 2 (CO₂) emissions which are calculated through the division of the total Scope 1 and 2 emissions by the number of passengers. In addition, carbon offsets purchased by the airport for the airport's Scope 1 emission sources are deducted for intensity calculation purposes. Sydney Airport's emissions intensity per enplaned passenger excludes passengers using the airport's Terminal T3 (Sydney Airport Limited, 2020e).

Figure 6. Sydney Airport's total annual emissions intensity per enplaned passenger ((kgCO₂e)) and year-on-year change (%): 2013-2019 Legend: PAX= Passenger Source: Sydney Airport Limited (2016b, 2020e)

4.6. Sydney Airport annual carbon offsets

Figure 7 presents the annual trends in total carbon offsets (tCO₂e) by Sydney Airport for the period 2013 to 2019. Carbon offsets that deliver socio-economic benefits are used by Sydney Airport to offset emissions that can no longer be feasibly managed through the airport's energy efficiency, or through renewable purchase and generation strategies (Sydney Airport Limited, 2020e). During the study period, Sydney Airport offset its carbon emissions through the "Greenfleet" program (Sydney Airport Limited, 2016b, 2020e). "Greenfleet" is a not-for-profit environmental organization whose aim is to protect the climate through forest restoration. The organization plants native biodiverse forests to offset carbon emission from its supporters (Greenfleet, 2020). As can be seen in Figure 7, Sydney Airports total carbon offsets remained constant at 430 tCO₂e during 2013, 2014, and 2015, respectively. The largest decline in total annual carbon offsets (tCO₂e) occurred in 2016 when total carbon offsets declined by 31.39% on the previous year levels. During the period 2016 to 2018, Sydney Airport's total annual carbon offsets remained constant again, with a small annual increase of 0.33% being recorded in 2016 (Figure 8). Figure 7 shows that there was a significant increase in the total annual carbon offsets (165.76%) in 2019. In 2019, Sydney Airport continued to purchase offsets for emissions from its car fleet and expanded the program to include the airport's non-electric landside bus fleet and employee travel (Sydney Airport Limited, 2020e).

Figure 7. Sydney Airport's total annual carbon offsets (tCO₂e) and year-on-year change (%): 2013-2019 (Sydney Airport Limited 2018b, 2020e)

4.7. Sydney Airport carbon reduction initiatives

During 2014, Sydney Airport implemented a range of initiatives to reduce its carbon footprint. The energy saving measures included the installation of LED lighting in floodlights, aerobridges, street lighting, car parks, taxiways, and a number of areas within the airport terminals. The airport also installed movement sensors in some of its passenger aerobridges. Other energy saving measures included the installation of variable speed drive pumps for the airport's recycled water treatment plant, and the introduction of a gas fired hot water service (with recycled water provisions) to service the airport's new bathroom facilities. Also, during 2014, Sydney Airport replaced its existing chillers with four high-efficiency variable-speed chillers. The airport also upgraded its Terminal 1 chilled water system and air handling systems (Sydney Airport Limited, 2015b).

During 2015, Sydney Airport undertook works that were aimed to improve the energy efficiency of its retail spaces and the specific energy efficiency measures included more energy efficient lighting (Sydney Airport Limited, 2016b).

As previously noted, the ground service equipment (GSE) used at airports produce harmful emissions, and hence, impact air quality at the airport (Budd, 2017). There are several electrification strategies available to airports to achieve emissions reductions. These include the electrification of ground service equipment (GSE) and the electrification of airport support vehicles, for instance, shuttle buses (Gellings, 2011). During 2016, Sydney Airport continued to adopt an electrification strategy for ground service equipment (GSE) and support vehicles operating across the airport. In 2016, the airport introduced electric buses as part of the airport's parking and ground transport operations. A total of six buses were used on the bus route linking terminals T2 and T3 and the Blue Emu car park. In 2016, the airport explored the potential to source electricity to power the electric buses through solar or other green energy sources. Sydney Airport also installed additional charging equipment for electric ground service equipment (GSE) operating at the airport (Sydney Airport Limited, 2017b).

In 2017, Sydney Airport enhanced its delivery of energy demand management opportunities. This was achieved through lighting upgrades, rationalisation of air conditioning set points, a building energy optimisation program, and the upgrading of the airport's baggage handling system components such as motors and conveyor belts to more energy efficient alternatives. During 2017, the airport continued its transition to the use of low carbon equipment with the introduction of electric buses. The airport also installed its first solar photovoltaic system on the top of the car park at the T1 International passenger terminal. During the system's peak generation, 30% of the power will serve the terminal's power demand, and the remaining 70% is fed back into the grid for Sydney Airport's use. Also, during 2017, Sydney Airport continued to work collaboratively with its airline customers to improve overall airport efficiency and reduce land-based fuel burn (Sydney Airport Limited, 2018b).

In February 2018, Sydney Airport's 550 KWh rooftop solar system was commissioned on the P6 Terminal 1 car park. In 2018, Sydney Airport ratified a "Corporate Power Purchase Agreement" for sourcing up to 75% of electricity load from wind energy (Sydney Airport Limited, 2019b). The use of wind power offers an airport a range of important environmental benefits. Wind is regarded as a clean,

inexhaustible, and environmentally friendly energy source that can provide an alternative to fossil fuels in order to enhance air quality and reduce greenhouse gases (Tong, 2010).

In 2018, Sydney Airport implemented a “Ground Power Improvement Program” with airlines to increase the utilisation rate of Fixed Electrical Ground Power Unit (FEGPU) and Preconditioned Air (PCA). The program also aims to minimise Auxiliary Power Unit usage and fuel burn at the airport. The “Ground Power Improvement Program” included the planned provision of FEGPU and PCA at all gates and remote stands. During 2019, Sydney Airport continued to provide airport infrastructure to support an increased utilisation rate of Ground Power Units (GPU) and Pre-Conditioned Air (PCA) as well as the minimization of aircraft Auxiliary Power Unit (APU) usage. The environmental benefits of this strategy are reduced carbon dioxide (CO₂) and nitrous oxide (NO_x) (Sydney Airport Limited, 2020e).

During 2019, Sydney Airport continued its lighting replacement program in the airport’s passenger terminals, upgrading LED lighting in wayfinding signage at terminal T1. The airport also upgraded airfield and landside lighting systems. These upgrades included the installation of a new lighting control system in the baggage reclaim halls which enables the airport to switch to power savings modes during curfew periods. Sydney Airport also completed the replacement of its taxiway and stop bar signs with LED lights (Sydney Airport Limited, 2020e).

Also, during 2019, Sydney Airport reviewed the use of moving walkways and escalators to reduce energy consumption. Sydney Airport reduced the overall number of pool cars in its fleet during 2019 and replaced three petrol cars with more environmentally friendly hybrid electric cars (Sydney Airport Limited, 2020e).

4.8. Sydney Airport future carbon reduction initiatives

Sydney Airport is committed to having a 100% per cent electric landside bus fleet by the end of 2021. The airport’s electric buses will deliver carbon emission reductions in the long term and improve local air quality through zero tailpipe emissions. Other environmental benefits associated with an all-electric bus fleet include lower external noise levels, reductions in waste fluids to zero and a decrease in the amount of toxic material generated during servicing of the vehicles. Sydney Airport is also aiming to increase its owned airside electric vehicle use to 50% by the end of 2021 (Sydney Airport Limited, 2019). The airside means the movement area at an airport, adjacent terrain, and buildings/infrastructure, or portions thereof, the access to which is restricted (Rossi Dal Pozzo, 2015).

In addition, Sydney Airport continues to work closely with its business partners to further support the electrification of the airside ground service equipment (GSE) fleet. A smooth transition to the use of electric equipment is a key component of Sydney Airport’s Airside Operations Licence (AOL). The transition from diesel powered equipment to electric will continue to deliver future environmental and health benefits for airport workers on the airfield and in the baggage handling rooms. Furthermore, the airport is also incorporating infrastructure required to support electrification of the airside vehicle and GSE fleet into planning and design for new airport-related developments. This includes forward planning to incorporate charging stations for electric vehicles and ground service equipment (GSE) at the airport. The airport is also continuing to work with tenants who wish to install charging stations for electric vehicles on the airport (Sydney Airport Limited, 2020e).

In recent times, there has been a growing trend by airports and airlines to use aviation biofuel as an environment sustainability measure (Baxter *et al.*, 2020). Sydney Airport has acknowledged the role sustainable aviation fuel can play in the aviation sector and the importance of its support for solutions, technologies and the infrastructure required to enable this transition to the use of sustainable aviation fuels. As an infrastructure provider the airport will help facilitate the use of these fuels at Sydney Airport (Sydney Airport Limited, 2020e).

A key step in the airport’s pathway to achieving carbon neutrality is improvements in its fuel and energy efficiency and to continue to grow onsite renewable power generation (Sydney Airport Limited, 2020e).

5. Conclusions

In conclusion, this study has investigated the strategies and measures that can be defined and implemented for a major airport to achieve its goal of being a carbon neutral airport. To achieve the objectives of the study, Sydney Airport was selected as the case airport. The research was undertaken using an in-depth qualitative instrumental case study research approach. All the data collected for the study was examined using document analysis. The study was underpinned by a case study protocol and research framework that followed the recommendations of Yin (2018).

As previously noted, in recent years, Sydney Airport has implemented a wide range of carbon reduction initiatives. These carbon reduction initiatives underpin the airport's goal of being carbon neutral by 2025. The carbon reduction initiatives include the widespread installation of LED lighting in the landside and airside precincts. This initiative also included upgraded airfield and landside lighting systems. The airport also installed movement sensors in some of its aerobridges. In the study period, Sydney Airport also introduced a new gas fired hot water system, that included recycled water provisions, to service the airport's new bathrooms. The airport's chillers were upgraded with new, high efficiency, variable-speed chillers. Sydney Airport's recycled water plant was upgraded with the installation of new more efficient variable speed drive pumps. One of the most significant carbon reduction measures implemented by Sydney Airport has been the electrification of airport support vehicles and ground service equipment (GSE). The key environmental benefit from the electrification of vehicles and ground service equipment (GSE) is the reduction in harmful emissions. The case study revealed that Sydney Airport has applied its electrification strategy to its own fleet of vehicles and buses and has also worked closely with its key stakeholders to ensure that they too adopt this electrification strategy for their GSE and ground support vehicles. Sydney Airport will also be incorporating the required infrastructure to support the electrification of ground vehicles and ground service equipment (GSE) into the planning and design for new airport-related developments. Another important carbon reduction measure has been the installation of a solar power photovoltaic system at the airport. Around 30% of the solar power photovoltaic system power generation is used to power a passenger terminal power demand with the remaining 70% being fed back into the grid for Sydney Airport's use. A further significant carbon reduction measure was Sydney Airport's 2018 "Corporate Power Purchase Agreement" which provides for the provision of 75% of electricity load from wind energy. Wind power is regarded as a low carbon energy source.

During the study period, Sydney Airport introduced a "Ground Power Improvement Program", whereby fixed electrical ground power equipment and pre-conditioned air equipment were installed at airport gates in order to alleviate the necessity for aircraft, during the time they are on ground, to use their auxiliary power units (APU). An aircraft's auxiliary produces harmful emissions. Thus, the use of fixed electrical ground power and preconditioned air eliminates these harmful emissions from the environment. The final carbon reduction measure identified in the case study is Sydney Airport's recognition of the important environmental benefits of sustainable aviation biofuels and as an airport operator, Sydney Airport will help to facilitate the usage of such fuels by the airports providing services to and from the airport.

Over the study period, the annual emissions intensity per enplaned passenger (kgCO₂e) exhibited a consistent downward trend, with a decrease being recorded in each year of the study. This was despite the passenger volumes growing at Sydney Airport over the study period. The largest single decline occurred in 2016 (10% decrease).

At the time of the current study, carbon neutrality represented the highest level of carbon management performance under the Airports Council International "Airport Carbon Accreditation Program". In order to achieve this level of accreditation, airports are required to reduce carbon dioxide (CO₂) emissions from those sources that fall under their control as much as possible. Airport also need to compensate for the residual emissions with investment in high-quality carbon offsets. Sydney Airport was awarded Accreditation Level 1 in May 2014. During 2015, the airport was awarded Accreditation Level 2, and this was followed in 2016, with the airport being awarded Accreditation Level 3. At the time of the current study, Sydney Airport held Accreditation Level 3. The Airport Carbon Accreditation Program has underpinned the airports objective of being carbon neutral by 2025 as Sydney Airport aims to achieve Accreditation Level 3+: carbon neutrality by that date.

The case study revealed that during the study period, Sydney Airport had offset its annual carbon emissions through the "Greenfleet" program. "Greenfleet" is a not-for-profit environmental organization whose objective is to protect the climate through forest restoration. The case study also revealed that the Sydney Airport's total annual carbon offsets fluctuated over the study period. During the period 2013-2015, the total carbon offsets was 430 tCO₂e per annum. However, from 2016 to 2018, the total carbon offsets were around 295 tCO₂e per annum. There was, however, a very substantial increase in the total annual carbon offsets (165.76%) in 2019, with the total carbon offsets being 784 tCO₂e. The inclusion of the airport's non-electric landside bus fleet and employee travel contributed to the strong increase in carbon offsets by the airport in 2019.

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