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ENVIRONMENTALLY SUSTAINABLE AIRPORT ENERGY MANAGEMENT USING SOLAR POWER TECHNOLOGY: THE CASE OF ADELAIDE AIRPORT, AUSTRALIA

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Abstract: Airports are extremely energy intensive areas. To mitigate the environmental impact of energy usage and to reduce their reliance on the traditional fossil-based energy sources, many airports around the world have installed solar photovoltaic (PV) systems as part of their environmental sustainability policies. One such airport that has embraced solar photovoltaic (PV) power is South Australia-based Adelaide Airport, who have installed the largest roof-top photovoltaic system at an Australian airport. Using an in-depth exploratory case study design, this paper empirically examines the environmental benefits arising from the use of the system for Adelaide Airport and the solar photovoltaic (PV) ownership model adopted by Adelaide Airports Limited, the airport operator. The qualitative data was analyzed using document analysis. The study found that the solar photovoltaic (PV) system installed at Adelaide Airport has delivered tangible environmental benefits. The system has enabled the airport to not only reduce its energy consumption by approximately 10% but also has enabled the airport to reduce its carbon emissions by an estimated 915 tonnes CO_2-e. The system can offset 100% of the airport's short-term car park's electricity consumption, with the excess power being diverted to satisfy the other requirements of the airport.

Keywords: Adelaide Airport, airports, case study, energy, photovoltaic (PV) systems, solar power.

1. Introduction

Airports are a critical component of the complex international air transport system that supports and facilitates the movement of passengers, air cargo and tourism all around the world (Airports Council International, 2008). Over the past 20 years or so the awareness of the environmental impacts of human activity has increased substantially (Cowper-Smith and de Grosbois, 2011). Accordingly, the long-term survival of businesses is becoming increasingly dependent upon their ability to recognise and act upon societal and technological change (Fernando, 2011). Thus, businesses are under greater pressure to define and adopt more environmentally conscious practices and to operate in a sustainable manner (Coyle *et al.*, 2015). One of the greatest threats to the air transport industry, and, specifically, the airport industry's ability

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to grow and operate in the future is climate change (Preston, 2015). Due to this focus, the airport industry is confronting the impact of growing environmental pressure (Graham, 2014). Accordingly, there has been greater attention paid to the impact that airports have on the environment and airports are working to make themselves more environmentally responsive (Vanker *et al*., 2013). One of the most common energy-saving measures implemented by airports is the installation of solar powered photovoltaic (PV) panels on the roof space of airport buildings. Other energy-saving measures include building insulation, and lighting renovation using light emitting diodes (LEDs) (Kazda *et al*., 2015).

The major areas of energy consumption at airports are illumination (lighting), steam, heating systems, cooling systems, climate control systems, and comfort provision systems (Radomska *et al*., 2018). Airports need to have a constant supply of power throughout the year to sustain operations and satisfy key stakeholder requirements. New renewable technologies, such as solar and wind power, can be utilised to help satisfy airports energy demand (Hariprasad *et al*., 2017). The use of renewable energy resources has several advantages for airports. First, these systems tend to be low impact and, second, they provide an alternative source of power to operate the airport (Kramer, 2010). Renewable energy sources also produce very little waste (Yerel and Yayli, 2016). The use of solar power photovoltaic (PV) systems at airports appears to be most successful in decreasing airport ground emissions (Sukumaran and Sudhakar, 2017a).

The deployment of large photovoltaic (PV) arrays will provide an airport with both environmental and economic benefits (DeVault *et al*., 2014). This is because large-scale photovoltaic (PV) systems produce few CO_2 emissions, although their production, transport, installation, cleaning and decommissioning and recycling do create CO_2 emissions. Furthermore, PV systems have a life-span of 20 years or more. In addition, they require lesser amounts of maintenance and the system can be recycled (Wybo, 2013). An increasing number of airports located around the world have installed solar power systems (Lew, 2018). These include Cochin International Airport in India, which was the world's first totally solar powered airport (Menon, 2015; Sukumaran and Sudhakar, 2017b), Adelaide International Airport, Alice Springs Airport, Birmingham, Copenhagen Airport, Hong Kong International Airport, Indianapolis International Airport, Osaka's Kansai International Airport, and London Gatwick Airport are examples of airports that have introduced solar power systems.

The objective of this study is to examine the photovoltaic system installed at Adelaide International Airport and to determine the environmental benefits arising from the use of the system. The Adelaide International photovoltaic system was considered for this case study as it is the largest roof-top photovoltaic system installed at an Australian airport (Adelaide Airport Ltd, 2017a). Also, the case documentation was extensive and allowed for the in-depth analysis of the system.

The remainder of the paper is organized as follows: the literature review presented in Section 2 commences with a brief overview of airport energy management, airport energy sources, and a review of solar power as an airport energy source. The research method that underpinned the study is described in

Section 3. The empirical examination of Adelaide Airport solar power system is presented in Section 4. The key findings of the study are described in Section 5.

2. Background

2.1. Airport Energy Management

Airports are extremely energy-intensive areas (Akyüz *et al.*, 2017; Baxter *et al.*, 2018; Ortega Alba and Manana, 2017). This is due to the large buildings (both passenger terminals and non-passengers' areas) that are equipped with heating and air-conditioning systems, and the high-power demand for lighting and electric equipment and the energy requirements from the many facilities located within the airport precinct (Cardona *et al.*, 2006). Air conditioning systems represent a substantial portion of airport's energy consumption (Gomri and Mebarki, 2016). Around 70% of the energy that is consumed in airport terminal buildings is utilized for air conditioning, cooling and heat purposes. This rate can be higher in countries that a cold climate (Akyüz *et al.*, 2017).

In addition to the provision of electrical energy required for the aids to air transport operations, electrical energy is also required for airport buildings, aircraft hangers and other airport facilities (Kazda *et al.*, 2015). Thus, energy management, which includes heating, ventilation, air conditioning, and lighting, is extremely critical for airports (Graham, 2014). Airports also require a guaranteed, appropriately priced, and secure energy supply that can meet the peak demand from their service partners and passengers, and thus, optimize their operational capacity. The maintenance of an ambient temperature and air quality within airport passenger terminals to ensure passenger comfort typically represents the single most significant contribution to energy usage and management at most airports (Thomas and Hooper, 2013).

2.2. Airport Energy Sources

To be able to undertake an airport's landside and airside activities, a certain amount of energy is required. The two key energy sources are electricity and fuel, such as, diesel, natural gas, and propane (Ortega Alba and Manana, 2016). Electrical energy is typically sourced from various sources and is supplied directly to the airport through dedicated sub-stations (Janić, 2011). Usually, airport electricity supplies are sourced from the commercial grid and are supplied by a power company (Ortega Alba and Manana, 2016, p. 349). This energy is principally consumed for heating, cooling, lighting, and operating the airport's facilities, equipment, and other devices in the processes of servicing passengers and their baggage and air cargo consignments in passenger and cargo terminals, respectively. Electrical energy is also consumed in the provision of heating, cooling (air conditioning), and lighting other administrative buildings at airports. Crude oil is typically used for producing the gasoline that is used to power the ground vehicles used in an airport's airside and landside areas (Janić, 2011). Fuel is also used for heating boiler systems, emergency generators or vehicles (Ortega and Manana, 2016).

To ensure that energy demand can be satisfied when the key stakeholders energy requirement arises, whilst at the same time reducing their long-term operating costs, airports located all around the world are placing a greater focus on energyconservation measures in the design (and operations) of terminal buildings and airport infrastructure (Thomas and Hooper, 2013). Some airports have also developed and operate new power-generation systems. These systems provide airports with reliable and affordable sustainable energy whilst also delivering energy cost savings (Budd and Budd, 2013; Ortega Alba and Manana, 2016).

There are several energy technologies that are currently being developed as energy sources for airports, including solar photovoltaic, concentrating solar power, wind power, oil and natural gas extraction, steam-generated power production and electricity transmission (Barrett *et al*., 2014).

- Traditional Power Plants — Traditional power plants utilize conventional fossil fuels and biofuels to produce steam which is used to drive a turbine to produce electricity. Due to the fuel, they operate on is always available (unlike renewable sources), these plants provide base load electricity to the electricity grid. Older plants operate with coal and oil, whereas newer plants typically utilize natural gas or biofuels, which comply with modern environmental regulations;
- Solar Photovoltaic (PV) Power System: a solar PV system is comprised of various components that collect the sun's radiated energy, convert it to electricity, and then transmit the electricity in a usable form. The main component of the PV system is the solar panel;
- Concentrating Solar Power Plants (CSP) — CSP systems utilize reflective mirrors in large arrays to focus the sun's energy on a fixed point producing intense heat, which is then subsequently converted to electricity. The most common means for producing electricity in these systems is to heat water and produce steam, which drives a turbine, normally for supplying commercial power to the grid; and
- Wind Turbine Generators and Farms (WTG) — WTGs convert air blowing across the earth's surface into electricity (Barrett and Devita, 2011, pp. 7-9).

Furthermore, airports regularly work closely with their tenants, concessionaires, and service partners to reduce energy consumption. This is achieved through the introduction and use of low-energy equipment and systems (Thomas and Hooper, 2013).

2.3. Solar Power as An Airport Energy Source

Renewable energy has become a progressively more cost-effective business option for airports because of technological advancement, market maturity, and public-sector investment in such systems (Barrett, 2015). The production of solar power energy onsite at an airport alleviates the influence of global energy markets. This is especially important for the air travel industry as airline profits are significantly influenced by jet fuel costs. An increase in ground-based energy costs may result in airports charging higher aircraft landing fees. In such cases, airlines often pass these costs on in the form of higher prices or additional usage fees (Lew, 2018).

The amount of power that a solar PV system can produce at an airport is dependent upon the available area (Sukumaran and Sudhakar, 2017a) and is also dependent upon the type of system, the system's orientation, and the available solar resource, that is, the amount of the sun's energy reaching the earth's surface (Kandt and Romero, 2014). One of the critical issues that needs to be addressed in developing large-scale PV systems is an appropriate location: flat, secured from possible vandalism and thieves, and located near to existing power lines (Wybo, 2013). Typically, airports may have substantial amounts of open space that could be used for the installation and operation of a PV system (Baek *et al*., 2016; Curran, 2016). In addition, many airports have mandatory free spaces, which are referred to as sound buffer zones, and these are an ideal location for a solar power plant (Sukumaran & Sudhakar, 2017b). Airports areas often satisfy these constraints so consequently a growing number of airport authorities are installing or planning to install large surfaces of PV panels that can produce 20MWh or more (Wybo, 2013).

Airports have some favourable characteristics that enhance the financial viability of on-site renewable energy, particularly for solar photovoltaics (PV). Airport land and buildings can provide suitable sites for solar facilities that otherwise do not generate financial benefit. The open landscape and geographic position of airports necessary for safe airport management also facilitates the capture of natural resources that fuel renewable energy. In addition, renewable energy can directly supply an airport's on-site energy consumption needs, decreasing defraying costs in the future as off-site energy purchasing is curtailed (Barrett, 2015). An airport's carbon footprint (CO_2 emissions) can also be reduced through the substitution of solar PV based power generation (Sukumaran and Sudhakar, 2017a; Wybo 2013).

2.4. Solar Photovoltaic System Components

Solar photovoltaic (PV) systems are customised depending upon the requirements of the site. There are different environmental factors at each site. These factors will influence the type of system required and its level of performance. PV systems include the following components:

- The solar resource – the sun is the power source for all PV systems;
- Photovoltaic cells – when treated with chemical impurities (this process is referred to as doping), these thin sections of semi-conductor material react to sunlight, creating voltage and current;
- Panel or module;
- Array – an array is comprised of multiple panels wired together in series and in parallel to provide specified voltages and current. (The array is typically fastened to a mounting structure);
- Battery – a battery can be defined as a direct current (DC) electrical energy storage device;
- Inverter – the DC-AC inverter converts direct current (DC) power into alternating power (AC);
- Charge controller – a charge controller regulates, charges and maintains battery voltage;
- Electrical load – this includes the appliances and other devices that use the energy generated by the PV system;
- Wiring – the PV system wiring includes the wires that are known as conductors that connect the system components to complete circuits; and
- Surge protector – this is a device that safeguards against electrical shock from short circuits and damaging power fluctuations (Balfour *et al*., 2013, pp. 4-5).

2.5. Siting Consideration for a Solar Photovoltaic System at Airports

Solar photovoltaic systems should be installed at an appropriate distance from the airport's runway(s) and adhere to all relevant safety and fire measures (Kandt and Romero, 2014).

2.5.1. Solar Photovoltaics (PV) Performance

Ideally, a solar installation would be in an unshaded location with an optimum tilt angle (normally equal to latitude). Importantly, not all airport sites are conducive for solar technologies (Kandt and Romero, 2014).

2.5.2. Minimizing Glare and Glint from the Solar Photovoltaics (PV) System

The use of solar photovoltaic (PV) systems at airports can impact on pilots, air-traffic controllers, aircraft, and air navigation systems due to the glare reflection (Mostafa *et al*., 2016). The likely impacts of a solar system PV module reflectivity could result in either glint or glare, or possibly both. This may result in a brief loss often vision, which would be a safety concern for aircraft pilots (Anurag *et al*., 2017). Consequently, glare due to the reflection of sunlight from the metal parts of a solar PV panel could potentially provide a risk that could affect aviation safety (Mostafa *et al*., 2016). There are several measures that can be used to mitigate the glare from the solar system: the application of anti-reflective coatings (Solanki and Singh, 2017) and/or surface texturing of the systems panels (Ahmed *et al*., 2017). Neither of these measures have a discernible impact on the solar PV system performance but could assist in helping to minimize reflection (Kandt and Romero, 2014).

2.5.3. Impact on Wildlife

There are several concerns of the impact of solar PV systems on wildlife and these include whether the presence of the solar PV system structures and any associated human activity will disturb local wildlife to the extent that the wildlife will avoid the area, and consequently, whether this will have a detrimental effect on the wildlife in the area. There are also some other concerns that are unique to solar energy facilities. According to the United States Fish and Wildlife Service (2018), "the reflective surfaces of the mirrors and solar panels may appear to a flying bird to be a body of water". Miller (2018) has further noted that when insects, birds or bats fly through the solar beams generated from the solar PV system, they are ignited in mid-air, creating a plume of smoke, or streamer. Also, these animals may die from the heat, by the force of falling to the ground, or by a waiting predator (Miller, 2018). In addition, deaths and injuries to birds colliding with solar PV system's mirrors and panels is a potential problem that should be considered when installing a solar PV system (United States Fish and Wildlife Service, 2018).

3. Research Method

The research undertaken in this study was exploratory in nature (Farquhar, 2012; Yin, 2017). Data for the study was obtained from a variety of documents, annual reports, press releases, company materials available on the internet and records as sources of case evidence. Documents included Adelaide Airport's annual reports, solar system fact sheet, press releases, and the airport's websites. Documents were also sourced from the leading airport industry trade magazines and websites. Thus, this study therefore used secondary data. The study followed the three principles of data collection as suggested by Yin (2017), that is, the use of multiple sources of case evidence, creation of a database on the subject and the establishment of a chain of evidence.

Document analysis was used to analyse the documents gathered for the study. Case studies often use document analysis (McNabb, 2013; Oates, 2006; Ramon Gil-Garcia, 2012). Document analysis focuses on the information and data from formal documents and company records collected in the study (Andrew *et al*., 2011; Yin, 2017). Scott (2014) and Scott and Marshall (2009) suggest that there are four criteria that need to be taken into consideration when assessing the quality of historical documents: authenticity, credibility, representativeness and meaning. Before commencing the formal analysis of the documents that were collected for the study, the context in which the documents were determined, and the authenticity of the documents was carefully evaluated (Scott, 2003).

According to Chester (2016, p. 577), authenticity in document analysis refers to whether a document is genuine, complete, and reliable as well as being of unquestioned authorship. Authenticity also addresses whether their production is original, are not of questionable origin, and that they have not been subsequently altered. Once it has been determined by the researcher that the document is "genuine and of unquestionable origin," then the material can be considered "valid" as an artifact (Kridel, 2018).

Whilst any form of qualitative data may be original and genuine, that is, authentic in nature, it is possible that the content may still be distorted in some manner. Thus, a second criterion in appraising materials is determining their credibility and identifying whether the document's information is both honest and accurate (Kridel, 2018). Hence, credibility refers to the extent to which a document is sincere and not distorted and is free from error and evasion (Fulcher and Scott, 2011; Scott, 2014). In assessing this criterion, it is necessary for the researcher(s) to ascertain whether the document can be regarded as a credible, worthwhile piece of evidence and, also in some instances, whether it is accurate (Wellington, 2015).

A third criterion, representativeness, refers to the "general problem of assessing the typicality or otherwise of the evidence" (Scott, 1990, p. 7) collected for the study. A document's representativeness may become distorted over time. This is because with the passing of time the survival rate of certain materials becomes greater as the items may have been viewed as less valuable. Accordingly, the document(s) may have been stored away, rarely viewed following their point of origination, and hence, preserved. Furthermore, some important documents do not survive because their great significance caused them to become well used and worn. Consequently, they may be discarded while on the other hand less important documents survive because they attract so little use (Scott, 1990).

The fourth criterion, meaning, is a most significant aspect of document analysis (Fulcher and Scott, 2011). When conducting document analysis in a study, it is important to interpret the understanding and the context within which the document was produced. This enables the researcher to interpret the meaning of the document. The evidence found in the documents gathered and used for the study were all clear and comprehensible (van Schoor, 2017).

The document analysis was undertaken in six distinct phases as follows:

- Phase 1: This phase involved planning the types and required documentation and their availability;

- Phase 2: The data collection involved gathering the documents and developing and implementing a scheme for the document management;
- Phase 3: Documents were reviewed to assess their authenticity, credibility and to identify any potential bias;
- Phase 4: The content of the collected documents was interrogated, and the key themes, data and issues were identified;
- Phase 5: This phase involved the reflection and refinement to identify and difficulties associated with the documents, reviewing sources, as well as exploring the documents content; and
- Phase 6: The analysis of the data was completed in this final phase of the study (O'Leary, 2004; p. 179).

All the documents collected for the study were stored in a case study database (Yin, 2017). All the documents collected and analysed in the study were in English. Each document was carefully read, and key themes were coded and recorded (Baxter and Srisaeng, 2018). This study was also guided by the recommendation of van Schoor (2017), who has observed that to avoid bias in a study, documents of various sources should be analysed. Triangulation of documents was also used to add discipline to the study. One of the principal 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. Thus, in this study, data triangulation was used with the documents being collected from various sources. Triangulation helped to verify the themes that were detected in the documents that were collected, analysed and coded in the case study (Morris, 2017).

4. Case Study Results

4.1. A Brief Overview of Adelaide Airport

Adelaide Airport is located around six kilometres west of Adelaide's central business district (CBD). The airport's western boundary is one kilometre from the shores of Gulf St. Vincent. The airport occupies a site of around 785 hectares and is well-linked to the City the City of Adelaide, surrounding suburbs, and other major locations in South Australia through road links (Adelaide Airport Limited, 2014b). Adelaide Airport is Australia's fifth busiest domestic airport and sixth largest international airport (Adelaide Airport Limited, 2018b).

In May 1998, Adelaide Airport Limited purchased the operating leases of both South Australia-based Adelaide and Parafield Airports. The operating lease was for a period of 50 years with the option to extend the lease for a further 49 years (Adelaide Airport, 2017b). The company's major shareholders are Unisuper (49%), Statewide Super (19.5%), Colonial First State (15.3%), Industry Funds Management (12.8%) and Peron Investments (3.4%). Adelaide Airport has four subsidiary companies that are each 100% owned by the company: Parafield Airport Limited, Adelaide Airport Management Limited, New Terminal Financing Company Pty Ltd, and New Terminal Construction Company Pty Ltd (Adelaide Airport Limited, 2017b).

Adelaide Airport presently operates a two-runway system which is comprised of the main runway (RWY 05/23) which is 3,100 metres in length, as well as a secondary runway (RWY 12/30) which is 1,652 metres in length and 45 metres in width (Figure 1). The airport's primary main runway accommodates larger, long-haul, wide-body international aircraft, as well as smaller domestic and regional aircraft. The cross-runway is restricted by its length to regional aircraft and some domestic operations (Figure 1). However, this cross-runway can accommodate larger aircraft types, for example, the Airbus A330 aircraft (up to International Civil Aviation Organization Aircraft Code D) for landing only. The airport's existing passenger terminal, which was opened in 2005, comprises a 3-level facility of approximately 33,000 square metres (Adelaide Airport Limited, 2014b, pp. 78-79).

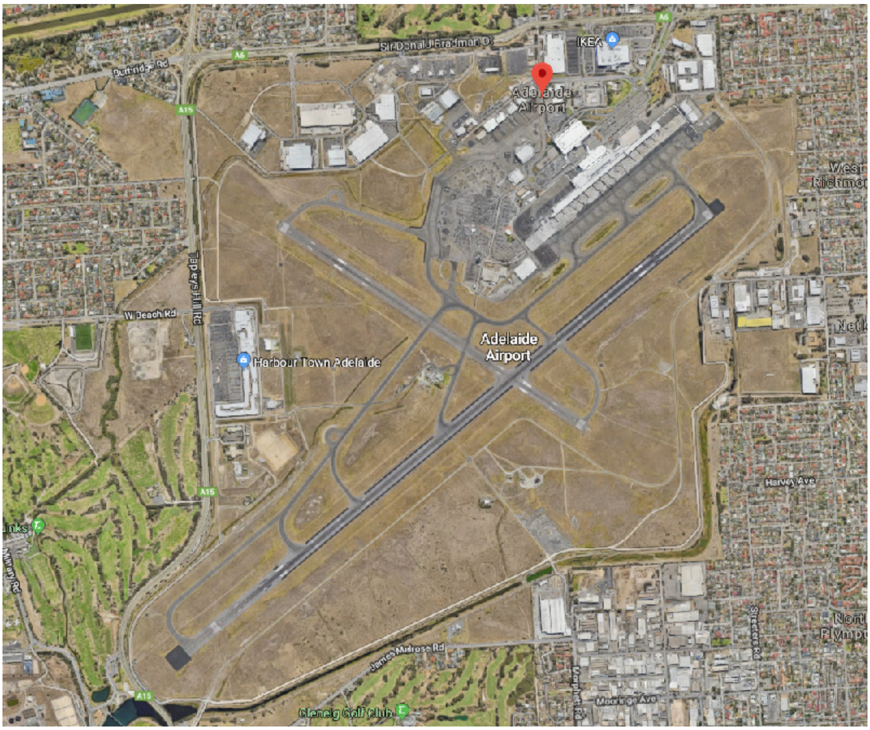

Fig. 1.
Aerial View of Adelaide Airport's Layout
Source: Imagery ©2018 Google, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, Map Data©2018 Google.

Qantas Airways and Virgin Australia are the two major full-service network carriers [FSNCs] serving Adelaide Airport. Domestic services are also provided by the two low-cost carriers [LCCs] Jetstar Airways and Tigerair. Nine international airlines operate services to and from Adelaide International Airport (Adelaide Airport Limited, 2018a). In addition to its international and domestic services, Adelaide Airport also acts an important hub for regional services to key towns located in New South Wales, South Australia and Victoria.

Figure 2 presents Adelaide Airport's total annual enplaned domestic and international passengers for the period 2007 to 2017. As can be observed in Figure 2, domestic passengers represent the largest source of passenger traffic at the airport. It is important to note, however, that airline passenger traffic fluctuates due to economic recessions or other major exogenous events (Graham and Ison, 2014), such as the 2008/2009 global fiscal crisis (GFC). Also, as can be seen in Figure 2, there was a decline in domestic traffic during the 2011/2012 financial year. This was a result of the lingering effects of the Chilean volcano ash cloud resulted in adverse conditions prevailing over a period of several weeks during the 2011/2012 financial year. This resulted in an unprecedented number of flight cancellations. This combined with the cessation of services by the low-cost carrier Tiger Airways (Tigerair have subsequently reinstated services to Adelaide), caused a downward turn in the domestic market (Figure 2) (Adelaide Airport Limited, 2013). Following the downturn in domestic passenger traffic in 2012, the airport has seen positive annual traffic growth over the period 2013-2017. During the period 2007 to 2017, there has also been growth in the number of annual enplaned international passengers (Figure 2) as well as the number of international airlines serving Adelaide Airport. For example, during December 2016, China Southern Airlines launched services from Guangzhou to Adelaide. In June 2017, Fiji Airways commenced non-stop services from Nadi, Fiji to Adelaide (Adelaide Airport Limited, 2017b).

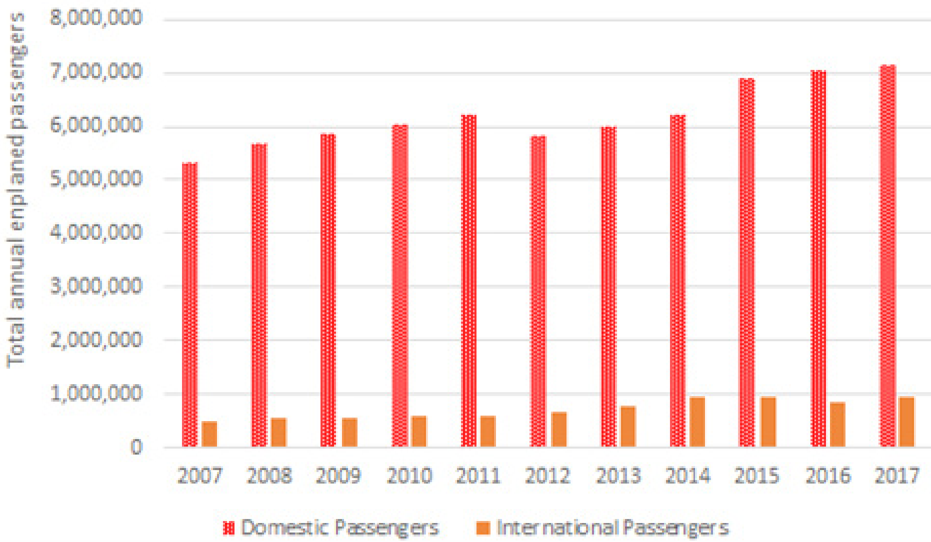

Fig. 2.
Adelaide Airport's Total Annual Enplaned Domestic and International Passengers: 2007-2017
Source: data derived from Adelaide Airport Limited (2009, 2010, 2011, 2012, 2014a, 2016, 2017b).

4.2. Adelaide Airport Environment Statement and Sustainability Policy

Adelaide Airport has published and implemented an Environment Statement that comprises eight key objectives:

- Ensure compliance with all relevant regulatory requirements and other requirements as well as the Company's 5-year Airport Environment Strategy (Young, 2014a);
- Implement and maintain an Environment Management System (EMS) (Young, 2014a). An environmental management system (EMS) is part of a firm's management system that is used to develop and implement the firm's environmental policy and to manage its environmental aspects (Rashid and Shami, 2017);
- Employ a continuous improvement approach to environmental sustainability (Young, 2014a);
- Promote environmental sustainability to the airport's key stakeholder who include customers, partners, tenants, contractors and suppliers;
- Positively engage with the local community;
- Monitor, audit and report on environmental performance against set objectives and targets;
- Communicate the Company's environmental sustainability vision and policy to the company's employees; and
- Conform to the ISO 14001 Environmental Management Standard (Young, 2014a). Note that the ISO14001 standard defines "the procedural requirements concerning the type of policy, plans, organizational practices and control mechanism to be adopted by companies to manage the activities better that can have a significant environmental impact" (Heras-Saizarbitoria *et al.*, 2018, p. 110).

In addition, to its Environment Statement, Adelaide Airport has also adopted a comprehensive Sustainability Policy. The airport's vision is to be a top tier Airport Business Centre in the Asia Pacific region, that is recognized for delivering exceptional outcomes to its customers, partners, shareholders and the broader community. The airport is striving to deliver high quality facilities and services that are being viewed as best practice, safe, secure and sustainable. As such Adelaide Airport Limited (AAL), the airport operator, is committed to managing and developing both Adelaide and Parafield Airports in a sustainable manner (Young, 2014b).

Adelaide Airport Sustainability Policy comprises seven key objectives:

- Integrate the principles of sustainable development and sustainable business practices into the company's planning, design, construction and procurement;
- Apply a stewardship approach throughout the company's supply chain by encouraging and facilitating the adoption of sustainability principles and practices by the company's customers, partners, tenants, contractors and suppliers;
- Minimize the environmental impact of the airport's operations through a program of continuous improvement, that always strives for innovative solutions to satisfy company goals
- Measure, reduce and manage the carbon emissions produced at the airport(s) on an ongoing basis with a strong focus on energy and fuel efficiency;
- Optimize community outcomes through the engagement with and supporting

the local community in a positive and constructive manner and being a valued member of the community;
- Ensure the company provides a positive and safe work environment, where employees are valued and equipped with the skills to effectively perform their work; and
- Ensure compliance with all relevant regulatory and other requirements (Young, 2014b, p.1.).

4.3. Adelaide Airport Membership of the Airport Carbon Accreditation Scheme

In the global air transport industry, several organizations and programmes have been established to assist airports in reducing their carbon emissions. Such programmes aid airports to establish systems to identify, monitor and reduce sources of air pollution (Vanker *et al*., 2013). The *Airport Carbon Accreditation Programme*, for example, is an independent programme which enforces accreditation criteria for airports on an annual basis (Ritter *et al*., 2011).

On May 14, 2015, Adelaide Airport became the first Australian-based airport to be recognized by the Airports Council International "*Airport Carbon Accreditation Program*" for the airport's management and reduction in carbon emissions. Adelaide Airport Ltd (AAL), the airport operator, was certified as Airport Carbon Accredited at Level 3 – *optimization*. At the time of receiving its Airport Carbon Accreditation certification it was just the seventh airport in the Asia-Pacific region to reach this level (Airport Technology, 2015; Sadler, 2015).

Adelaide Airport's Sustainability and Low Carbon policies underpin the airport's approach to both its operations and the development of the airport. The Adelaide Airport Environment Plan focuses extensively on the ongoing reduction of the airport's carbon emissions and to the Airports Council International's "Airport Carbon Accreditation Program" (Adelaide Airport Limited, 2014b, p. 3). The airport sets carbon and energy reduction goals in each five-year Airport Environment Strategy. The Airport Environment Strategy is developed in accordance within the requirements prescribed by the Australian Government's *Airports Act 1996* together with the Adelaide Airports Limited Sustainability Policy and Low Carbon Statement (Hogan and Bolt, 2016).

Energy usage at the airport represents around 85 per cent of its carbon footprint (Adelaide Airport Limited, 2014b; Hogan and Bolt, 2016). The inaugural 2014 *Carbon Management Plan* envisioned several carbon reductions projects. The large solar array project provided the airport with the greatest carbon abatement opportunities (around 8 per cent) albeit this was not the cheapest option. Notwithstanding, both the tangible and intangible benefits of the solar array system project looked like being an attractive investment for the airport (Adelaide Airport Limited, 2014b, p. 3).

4.4. Adelaide Airport Solar Power (PV) Systems: A Brief History

In 2007, Adelaide Airport installed its first solar power panels on the roofs of the airport's domestic and international terminal buildings (Australian Aviation, 2015; Douetil, 2015). Adelaide Airports Limited, the airport operator, announced in December 2015 that the company would be building Australia's largest airport rooftop solar power system (Australian Aviation, 2015). The project was completed in March 2016. In 2016, Adelaide Airports Limited set a goal to reduce the passenger electricity consumption by 10 per cent and the corresponding greenhouse gas emissions by 2019 (Hogan and Bolt, 2016). The airport's solar power photovoltaic system (PV) installed on the short-term car park is examined in the following sections.

4.4. Adelaide Airport Short-Term Car Park Roof Solar Power (PV) System

4.4.1. Solar Power (PV) System Technology

The rooftop solar photovoltaic (PV) system at Adelaide Airport was more than ten times the size (1.17MW) of the existing system that was installed in 2007 on the airport's short-term car park roof, thus bringing the total rooftop capacity to 1.28MW (Douetil, 2015). The PV system occupies 8,000 square metres of roof space. The total project cost was $AUD 2.45 million or $AUD 1.67/kWh. This resulted in an acceptable mid-term internal rate of return on investment of 13.1 per cent. The project also had a positive net present value (NPV) and a payback period of eight years, considering the movement in Australia's energy prices since the construction of the system, the airport expects that the forecast outcomes will be materially exceeded (Adelaide Airport Limited, 2014b).

The Solar PV system has 4,496 "*Trinasmart*" panels that possess the ability to operate on an independent basis through built-in "*Tigo Power*" optimizers. Consequently, each panel can operate at optimum (maximum) output irrespective of the partial shading that may occur on the solar array. During periods where panels are impacted by shade, the technology that has been deployed is able to increase energy output that is 20 per cent higher than conventional panels. In addition, each solar panel is independently monitored. The entire system can be shut down from a single switch, thereby significantly reducing arc and mitigating fire risk. Safety of the system was the highest risk issue for the airport (Hogan and Bolt, 2016).

Inverters are a key component of a solar photovoltaic (PV system) (Deambi, 2016; Libertini, 2014). The task of converting 1.17 MW of power from Adelaide Airport solar power photovoltaic system into electricity is performed by a bank of sixteen 60kW and two 20kW SMA "Sunny Tripower" inverters. The Adelaide Airport solar PV system was the first to use 60kW inverters. These inverters are specifically manufactured for commercial solar applications. Their selection for airport's solar PV system resulted in significant cost savings. They also reduced the area required to house the inverters by 75 per cent (Hogan and Bolt, 2016). According to Hogan and Bolt (2016), "the inverters are housed in a single custom-design, steel-frame room, utilizing ventilation from the building's existing perforated façade, thereby minimizing the interior heat load".

In addition, walkways and water outlets have been integrated in the solar PV system design so that any given panel is located within eight metres of a walkway. Also, the panels can be accessed for cleaning with a maximum 30-metre length of hose that has a broom attachment (Adelaide Airport Limited, 2014b).

4.4.2. Adelaide Airport Ownership Versus a Power Purchase Agreement (PPA) Model

Prior to examining the solar PV system ownership model adopted by Adelaide Airports Limited, it is important to note the ownership options that were available for consideration. A firm may decide to finance and operate the solar power PV system themselves or alternatively they may consider a power purchase agreement (PPA). According to (Gevorkian, 2016; p. 133), "long-term contract agreements where the electrical energy provider assumes total financing responsibility as well as maintenance of large-scale solar projects is also known as power purchase contract agreement (PPA)".

For Adelaide Airports Limited, a key decision that needed to be addressed in the infancy of the project's planning phase was to adopt an ownership model rather than a power purchase agreement (PPA). As previously noted, had the airport decided to utilize a PPA model, then a third party would have been responsible for the installation, operation, and maintenance of the system with no up-front cost to Adelaide Airport. In return, an agreement to purchase the electricity produced over a specified period at a pre-determined price would have needed to be negotiated. Adelaide Airport found that on a comparable basis, the full ownership model not only provided superior financial returns – especially given the dramatically increasing electricity prices in Australia – but also enabled the airport to retain control of its infrastructure and more closely manage the systems long-term maintenance costs (Hogan and Bolt, 2016).

4.4.3. The Associated Financial and Environmental Benefits of the Solar Power (PV) System

As noted earlier, one of the key environmental benefits of solar photovoltaic (PV) systems is they produce few CO_2 emissions (Wybo, 2013). The solar power (PV) system installed on the roof of Adelaide Airport's short-term car park roof has reduced the energy consumption and carbon emissions at Adelaide Airport by around 10 per cent (Australian Aviation, 2015). In addition, the system has been able to reduce the airport's carbon footprint by an estimated 915 tonnes CO_2-e. The significant carbon reduction has positively contributed to the airport achieving the Adelaide Airports Limited 2019 target (Adelaide Airport Limited, 2014b). Furthermore, the power produced from the solar PV system can offset 100 per cent of the airport's short-term car park's electricity consumption, with the excess power being diverted to satisfy the other needs of the airport (Navuluri, 2015). A further benefit of the solar PV system is that it satisfies investors' environmental, social and governance (ESG) risk expectations. The system has also helped the airport to increase its self-sufficiency and energy price certainty for a portion of energy demand, whilst at the same time, managing the risk of exposure to future price rise of fossil-based fuels and any future carbon policy impost. A further important benefit of the use of the solar power is that it has helped Adelaide Airport to enhance its reputation as a sustainable company/airport (Adelaide Airport Limited, 2014b).

Another important benefit of this project was that it offered the airport a financial incentive that, whilst not explicitly quantified, added recognizable value the business case. This included the deferral of any future purchase of additional peak demand from electricity retailers and, similarly, deferral of future investment in augmentation of the airport's inset electricity network (Hogan and Bolt, 2016).

4.4.4. Other Solar Power Photovoltaic Projects at Adelaide Airport

Following the success of installing and operating the solar power (PV) system on the short-term car park roof, Adelaide Airport has embarked on several other solar installations. These new installations include a 30kW array on a tenanted building in one of the airport's business parks and a further 30kW array on a staff occupied office building (Hogan and Bolt, 2016).

5. Conclusion

This study has examined, for the first time, the solar photovoltaic (PV) system installed on the short-term car park roof at Adelaide Airport. This is the largest roof-top photovoltaic system installed at an Australian airport. Despite the trend towards the installation and use of solar photovoltaics (PV) systems at airports all around the world, there has currently been relatively limited research undertaken on such systems at airports. Hence, this study adds some further valuable insights to the literature. The study used a qualitative exploratory case study research design. The data collected for the study was examined using document analysis. The qualitative case study was underpinned by the research framework that followed the recommendations of Yin (2017).

The study found that the solar photovoltaic (PV) system installed at Adelaide Airport has delivered tangible environmental benefits. The system has enabled the airport to not only reduce its energy consumption by approximately 10 per cent but also has enabled the airport to reduce its carbon emissions by an estimated 915 tonnes CO_2-e. The solar photovoltaic (PV) system can offset 100 per cent of the airport's short-term car park's electricity consumption, with the excess power being diverted to satisfy the other needs of the airport. Due to the success of the system, Adelaide Airport has identified other facilities where a solar photovoltaic system can be installed on the rooftop and which do not impact on the safety of operations at the airport.

Adelaide Airport's short-term car parking facility provided an excellent location to install the solar photovoltaic (PV) system. Other airports could also consider such a strategy. However, they would need to be cognizant of installing such a system where it does not produce glare which could potentially impact the safety of airport operations. The system should avoid glare for pilots and air traffic control (ATC) staff. In addition, the installation of a solar photovoltaic (PV) system should also consider the impact on wild life.

In the case of Adelaide Airport, the solar photovoltaic system (PV) helped the airport to meet investors' environmental, social and governance risk expectations and helps to mitigate the airport's exposure to future fossil-fuel based price increases. A further benefit of the system is that it has helped the airport to enhance its reputation as being a sustainable company/airport.

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