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Mitigating Aircraft Auxiliary Power Unit Carbon Dioxide (CO_2) Emissions During the Aircraft Turnaround Process from the Use of Solar Power at the Airport Gate: The Case of Moi International Airport, Kenya

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***Abstract*— *One of the most pervasive trends in the global airport industry in recent times has been the adoption of green renewable technologies. Many airports around the world have now installed photovoltaic (PV) solar systems as a key environmental measure. One of the critical areas of energy management at an airport is the provision of power and cooling at the gate, which is used during the aircraft turnaround process. Historically, the aircraft auxiliary power unit (APU) was the primary power source during the aircraft turnaround process. In recent times, airports have transitioned to the use of fixed electrical ground power (FEGP) and preconditioned air to mitigate the emissions from use of aircraft auxiliary power unit (APUs). Based on an instrumental case study research approach, this study has examined how Moi International Airport in Kenya has mitigated the airport's carbon footprint by using a green, renewable energy system. The study's qualitative data was examined by document analysis. The case study revealed that Moi International Airport has installed a photovoltaic (PV) solar system with a 500kW capacity that is used to primarily provide solar power at the airport's apron area. The photovoltaic (PV) solar system has delivered Moi International Airport with an important environmental related benefit as it has enabled the airport to reduce it carbon footprint, as the photovoltaic (PV) solar system has reduced the airport's carbon dioxide (CO_2) emissions by an estimated 1,300 tonnes per annum.*

Keywords*— *Aircraft turnaround process, Airport, case study, Moi International Airport, photovoltaic (PV) solar system, solar power, sustainable airport energy management.

I. INTRODUCTION

In the global air transport industry, there are many different types of airports. These include rural air strips, private air strips, military airports, small community airports, regional community airports, regional airports, major city airports, and hub airports (Meincke & Tkotz, 2010). These airports facilitate the movement of passengers, air cargo consignments, and aircraft through the provision of airfield infrastructure (runways, taxiways, and lighting systems) and passenger and air cargo terminal buildings. Airports provide the critical link between the air and surface transport modes (Baxter, 2021). However, a byproduct of air transport services at an airport are aircraft and ground service equipment (GSE) carbon dioxide (CO_2) emissions (Budd, 2017; Daley, 2010; Kazda et al., 2015). As a result, airports have a distinct carbon footprint (Postorino & Mantecchini, 2014). According to Wiedemann and Minx (2007, p. 5), "the carbon footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product". Climate change and carbon footprints are increasingly viewed as being the most urgent concerns confronting society and are now viewed as key issues of corporate responsibility (Hrasky, 2012). Airports are now under pressure to support the position that the industry should have a low carbon energy future (Ryley et al., 2013). Consequently, many airports have implemented extensive programs and strategies to mitigate the impact carbon dioxide (CO_2) emissions have on the environment (Mosvold Larsen, 2015). This has led to many airports implementing "green" or environmentally friendly policies and practices (Budd et al., 2015; Comendador et al., 2019; Sun et al., 2021).

An airport's carbon footprint can be reduced through the substitution of the conventional source of energy with solar PV based power generation (Sukumaran & Sudhakar, 2017a). This is because the atmospheric pollution from airport operations can be decreased through the consumption of renewable energy (RE)-based electricity generation (Sreenath et al., 2019). Considering this concern as to the adverse impact of their carbon footprint on the environment, many airports around the world have installed photovoltaic solar (PV) systems (Baxter, 2021). One such airport that has installed a photovoltaic (PV) solar system as a key environmental and energy-related measure is Moi International Airport, Kenya's Moi International Airport was the first airport in East Africa to install a photovoltaic (PV) solar system. Moi International Airport was also an early adopter of the use of solar power to provide power to aircraft during their turnaround process at the airport. The objective of this study is to examine the solar photovoltaic (PV) systems installed at Moi International Airport, Kenya and to identify the environmental benefits that the airport has gained from the use of this system. A further factor in selecting Moi International Airport, Kenya as the case airport was the readily available case documentation which allowed for the in-depth case study analysis.

The remainder of the paper is organized as follows: the literature review is presented in Section 2 and this establishes the context for the in-depth case study. The research method used in the study is described in Section 3. The Moi International Airport case study is presented in Section 4. The key findings of the study are presented in Section 5.

II. BACKGROUND

2.1 The Provision of Power to Aircraft During the Ground Turnaround Process

A variety of handling activities are undertaken at airports. The activities associated directly with the aircraft itself include the provision of power, cleaning, loading or unloading of baggage/air cargo (Doganis, 2005), lavatory services, aircraft marshalling, aircraft towing or pushback, and aircraft fueling (Ashford et al. 2013; Kazda & Caves, 2015; Thompson, 2007). Consequently, electrical power is required on the airport apron for the servicing of aircraft prior to engine start-up. External electrical power is also often used for aircraft engine start-up. The airport apron comprises the individual aircraft stands that interface with the airport terminal building(s) and where aircraft are ground handled in between flights (Budd & Ison, 2017). There has been growing pressure on airlines and airports in recent times to make their operations as 'green' as possible by minimizing unnecessary emissions (Lewis, 2018). Accordingly, many airports are now encouraging airlines to switch to using fixed electrical ground power units (FEGP) rather than running their aircraft's auxiliary power units (APUs).

With the two principal concerns of austerity and environmentalism becoming increasingly important at airports and other air installations, the requirement for and the use of ground power units (GPUs), auxiliary power units (APUs) and alternative power is evolving. Airports and airline operators are increasingly moving towards lower noise, lower emissions, lower fuel consumption, smart power conversion technology and alternative power such as fixed electrical ground power (FEGP) systems (Airside International, 2012). Indeed, the global community is currently paying greater attention to the impact that airports have on the environment. Consequently, airports are working to make themselves more environmentally friendly (Vanker et al. 2013).

Most aircraft can satisfy their energy requirements whilst they are on an airport ramp with an auxiliary power unit (APU) (Kazda & Caves, 2015). APU's are units that supply the essential requirements of the aircraft whilst it is on the ground at the airport and without the main engines operating, or when no external power source is available (Smith, 2004). These essential services include electricity, compressed air, and air-conditioning (Filippone, 2012).

Mobile ground power units (GPUs) are an alternative to the use of aircraft APUs. These provide DC and/or AC power to keep an aircraft powered up on the ground while its engines are switched off, as well as to start the machine's engines and APU. This equipment is typically diesel-powered but can be run off batteries. The second alternative to the use of ground power units (GPUs) is the use of fixed (installed), solid-state electrical power. This system significantly reduces emissions, which can have a substantial impact on local air quality. Fixed electrical power (FEGP) systems feed electricity to an aircraft straight from the local grid – though it is typically converted to 115V at 400Hz – and it is also possible to use pre-conditioned air (PCA) from the airport's own air system as an alternative to powering air-conditioning from an aircraft's auxiliary power unit (APU) (Lewis, 2018).

Hence, to minimize aircraft auxiliary power unit (APU) usage, many airports provide aircraft electric power (and also cooling capabilities) at the gate which are more efficient and cleaner than APUs (de Neufville & Odoni, 2013). Airports can help reduce aircraft emissions at airports through the provision of fixed electrical ground power (FEGP) and pre-conditioned air (PCA) at the gate to enable aircraft auxiliary power unit (APU) shutdown (Airports Council International, 2010). Hence, to satisfy more stringent regulations on the supply of power at aircraft stand, operators and manufacturers are increasingly working towards smarter, more efficient, and more environmentally friendly usage and deployment of power units (Airside International, 2012).

Although many aircraft have APU's that can provide power to the aircraft whilst it is on the ground, there is also a tendency by airlines to use ground electrical supply to reduce their fuel costs and to mitigate apron noise (Ashford et al. 2013). The requirement for these facilities has grown due to the costs associated with the provision of power and conditioned air to aircraft during ground servicing times at the apron gate by using the power generated from the aircraft's APU (Horonjeff et al. 2010).

2.2 An Overview of Photovoltaic (PV) Solar Systems and the Key Issues for Airports

The solar photovoltaic (PV) systems being installed at airports are typically customized. This customization enables the airport to optimize the use of their selected site (Baxter et al., 2019). Notwithstanding, there are different environmental factors that will be applicable for each site, and these factors will influence the type of photovoltaic (PV) system that is required, and they will also impact its level of performance (Baxter, 2021). Photovoltaic (PV) systems are comprised of the solar resource, photovoltaic cells, panel or module, array, battery, inverter, charge controller, electrical load – this includes the appliances and other devices that use the energy generated by the PV system, wiring and the surge protector – this is a device that safeguards against electrical shock from short circuits and damaging power fluctuations. The photovoltaic (PV) system wiring includes the wires that are known as conductors that connect the system components to complete circuits (Balfour et al., 2013, pp. 4-5). Quite often photovoltaic solar systems are collective in nature, that is, they are centralized systems that provide electricity to a group of users. These users include commercial customers (Bhattacharyya, 2015).

As noted earlier, in recent times airports have increasingly adopted the use of renewable energy sources (Sreenath et al, 2020, 2021a, 2021b; Sreejaya & Mubarak Abdullah Al-Haddabi, 2020). These include solar photovoltaic, concentrating solar power, wind power, oil and natural gas extraction, steam-generated power production and electricity transmission (Barrett et al., 2014). The use of renewable energy resources by airports has several favorable environmental related advantages. Green energy produces no greenhouse gas (GHG) emissions from the combustion of fossil fuels. Consequently, this reduces some forms of harmful air pollution (International Renewable Energy Agency, 2021; United States Environmental Protection Agency, 2021). Furthermore, renewable energy systems provide an airport with an alternative clean source of power (Kramer, 2010). As noted earlier, solar power photovoltaic (PV) systems lower the airport's ground emissions (Sukumaran & Sudhakar, 2017b). The airport's carbon footprint (carbon dioxide CO_2 emissions) can also be reduced by substituting solar PV based power generation for traditional, more heavily polluting, fossil-fuel based energy sources (Sukumaran & Sudhakar, 2017b; Wybo 2013). In addition, the use of green or renewable energy sources optimizes a firm's energy efficiency (Arman & Yuksel, 2013). Another environmental-related benefit is that renewable energy sources normally have very little waste (Yerel Kandemir & Yayli, 2016).

Many airports who have spare land are installing or plan to install large surfaces of PV panels (Figure 1). These photovoltaic (PV) solar systems are often capable of producing 20MWh or even higher amounts of sustainable energy (Wybo, 2013).

Fig.1: Solar photovoltaic system installed at Denver International Airport.

Photograph provided courtesy of Denver International Airport

III. RESEARCH METHODOLOGY

3.1 Research Method

This study used a qualitative instrumental case study research approach (Bullough Jr, 2015; Baker et al., 2015; Sorenson, 2021). An instrumental case study is the study of a case, for example, a firm(s) (Baxter, 2021). An instrumental case study provides researchers with insights into a specific issue, and enables researchers to redraw generalizations, or build theory (Stake, 1995, 2005). This research approach also facilitates the understanding of a specific phenomenon. An instrumental case study is designed around established theory (Grandy, 2010). The present study was designed around the established theory of solar power (Benda, 2018; Letcher, 2018; Mulvaney, 2019), and the use of solar power by airports [Baxter, 2021; Baxter et al., 2019; Sreenath, 2020, 2021a, 2021b; Sukumaran & Sudhakar, 2017a, 2017b).

3.2 Data Collection

Data for the study was obtained from a variety of documents, which included airport industry-related journals and magazines, newspaper articles, and company materials available on the internet. These documents were the source of the study's case evidence. This study used secondary data. The study followed data collection guidance of Yin (2018), that is, multiple sources of case evidence were used, a database on the subject was created, and there was of a chain of case evidence.

3.3 Data Analysis

Document analysis was the research technique used to analyze the documents gathered for the study. Document analysis focuses on the information and data from formal documents and company records that are gathered by the researcher(s) when conducting their case study (Andrew et al., 2011; Oates, 2006, Yin, 2018). The quality of the documents gathered for the study were assessed for their authenticity, credibility, representativeness, and their meaning (Scott, 2014; Scott & Marshall, 2009).

The document analysis process was undertaken in six discrete phases. Firstly, the types and required documentation and their availability were ascertained. In the second phase, the pertinent documents were collected and a system for managing them was developed. In the next phase, the documents were reviewed to assess their authenticity and credibility. It was also necessary to ascertain if any potential bias existed in the documents. The fourth phase involved the interrogation of the documents at which time the key themes, data and issues were identified. This was followed by a period of reflection and refinement at which time any difficulties with the documents were identified. Also, in this phase, a thorough review of the sources and the documents content was undertaken. The analysis of the data was finalized in the sixth phase of the document analysis process (O'Leary, 2004).

The study followed the suggestion of Yin (2018) in that all the documents gathered for the study were stored in a case study database. All the study's documents were in English. Each document was carefully read, and key themes were recorded in the case study (Baxter, 2021; Baxter & Srisaeng, 2020).

IV. RESULTS

4.1 A Brief Overview of Moi International Airport

Moi International Airport serves the city of Mombasa, which is located on Kenya's south-eastern Indian Ocean coast. The airport is operated by the Kenya Airports Authority (Centre for Aviation, 2021). Mombasa's Moi International Airport is Kenya's second largest airport (World Travel Guide, 2021). The airport is located on the Mombasa mainland off Port Reitz in the Vikombani area of Mombasa city. Mombasa city is in the coast province (Njeri Gitau, 2019). Moi International airport is served by more than eighteen airlines, which operate direct flights to Europe. Air services are provided to over twenty cities in the region (Kenya Airports Authority, 2021a).

Moi International Airport commenced operations as a small airstrip during World War II. The airport had two runways, and these were used to serve only Douglas DC 3 and similar sized aircraft. The Governments of Japan and Kenya undertook an expansion project between 1974 and 1977 to accommodate larger aircraft types. A new passenger terminal covering an area of 15,000m² was constructed as part of the project. The airport received its international status in 1978. The second passenger terminal was constructed over the period 1994 to1996 to handle the airport's increased passenger traffic volumes. Moi International Airport has four terminals, including two passenger terminals. Terminal 1 has international and domestic departures and arrival stations, whereas Terminal 2 only handles international departures. The other two terminals include a general aviation terminal, which is used for local departures to tourist destinations, airstrips and local airports and an air cargo terminal, which is used for handling international air cargo consignments (Airport Technology, 2014).

The airport also has a control tower, two hangars and service buildings for power and water supply. Moi International Airport has two runways. Runway 21/03 is 3,350 metres in length and 45 metres wide and Runway 33/15 is 1,260 metres long and 36 metres wide. The airport has ten aircraft taxiways, including taxiway A, a parallel taxiway that is 3,564 metres long and 23 metres wide, and taxiways B, C and D, which serve as 23metre-wide exit taxiways (Airport Technology, 2014).

4.2 Kenya Airports Authority Environmental Sustainability Policy

As previously noted, Moi International Airport is owned and operated by the Kenya Airports Authority. The Kenya Airports Authority has defined and implemented a comprehensive environmental sustainability policy. The company is fully committed to achieving the highest possible standards of environmental management performance across all areas of its business whilst at the same time ensuring safe and efficient aviation operations. In accordance with the policy, all the company's activities are planned and managed in an environmentally responsible manner that support the principles of sustainable development (Kenya Airports Authority, 2021b).

In operating, maintaining, and developing its portfolio of airports, Kenya Airports Authority is committed to:

- Complying with all relevant environmental legislation, regulations, and standards.
- Fostering an environmentally responsible culture amongst all the company's employees.
- Identifying, preventing, controlling, and minimizing adverse impacts on the environment caused by the company's operations by taking appropriate action(s).
- Kenya Airports Authority aims to engage and influence its stakeholders with a view of identifying, preventing, controlling, and minimizing adverse impacts on the environment caused by their activities and operations by taking appropriate action(s).
- The Kenya Airports Authority also implements specific measures and sets environmental objectives and targets to prevent pollution, minimize energy and materials consumption, conserve water and reduce waste at its source.
- The company also communicates its environmental management policies and performance to all employees, stakeholders, National Regulators, tenants, customers, and the community.
- The Kenya Airports Authority has developed, implemented, and maintains an Environmental Management System (EMS) in accordance with the ISO 14001: 2015 standard, which includes setting and reviewing all environmental objectives and targets (Kenya Airports Authority, 2021b). ISO 14001 is a worldwide meta-standard for implementing Environmental Management Systems (EMS) (Dentch, 2016; Grover & Grover, 2015; Heras-Saizarbitoria et al., 2011).
- The Kenya Airports Authority provides appropriate environmental training to all its employees, and third-party suppliers and contractors (as required), to enhance understanding of their responsibilities.
- Dedicating the staff and resources necessary to meet the company's environmental sustainability policy commitments.
- Incorporating environmental management objectives into the company's procurement process and improving environmental performance throughout the company's supply chain.
- Follow external trends and developments regarding the environment/sustainability
- The company also continually measures, monitors and reports the performance of the KAA' environmental management program and identifies opportunities for continual improvement
- The Kenya Airports Authority plans to obtain and maintain carbon neutrality (Kenya Airports Authority, 2021b).

The key areas of action by the company are:

- Energy use and reduction of the airport carbon footprint.
- Waste management.
- Community relations.
- Noise, air quality and water management.
- Transport and surface access; and
- Preservation of biodiversity (Kenya Airports Authority, 2021b).

4.3 Moi International Airport Photovoltaic (PV) Solar System

Kenya's Moi International Airport in Mombasa was the first East Africa-based airport to install a solar photo voltaic system (Bungane, 2018; Construction Review Online, 2018). The system was also the first of its kind in Africa (Njeri Gitau, 2019).

To ensure the sustainable development of Moi International Airport; the Kenya Airports Authority (KAA) through the Kenya Civil Aviation Authority received a grant for the installation of a "Solar Photovoltaic and Gate Electrification System". The solar power project was financed through International Civil Aviation Organization (ICAO)-European Union Assistance Project Capacity Building for Carbon Dioxide (CO_2) Mitigation from International Aviation (Njeri Gitau, 2019). Thus, the solar power project was part of a $7.36 million initiative implemented by ICAO and funded by the European Union targeting 14 countries — 12 of them from Africa — to reduce carbon emissions in the aviation sector (The East African, 2018). The actual Moi International Airport project cost was $USD 1.4 million. The procurement for the project was performed by the International Civil Aviation Organization (Njeri Gitau, 2019).

The photovoltaic (PV) solar system project commenced in 2018 and involved the installation of an airport gate electrification equipment system, that was comprised of a mobile electric-powered pre-conditioned air unit (PCA) and an electric power converter that will provide uninterrupted power to the PCA. It was envisaged that the project would take ten months to be completed (Construction Review Online, 2018). The Solar Photovoltaic and Gate Electrification System at Moi International Airport was commissioned in May 2019 (Njeri Gitau, 2019). This gate electrification equipment enables aircraft serving international flights to switch off their auxiliary power unit (APU) when they are parked at the gate and are being serviced in between flights (Njeri Gitau, 2019).

With the operation of the photovoltaic (PV) solar system, Moi International has two energy sources: the power from the photovoltaic (PV) solar system and electricity from the national grid (which has backup generators). These energy sources are connected via a distribution board into the main airport grid, where the electricity is subsequently linked to batteries that power the ground power unit and the preconditioned air unit. Electricity is also used to power other uses, for example, lighting (Mwangi, 2018).

The entire project consisted of a solar photovoltaic (PV) system of 500kW capacity that was connected to the airport terminal grid, an electric-powered pre-conditioned air (PCA) unit, an electric 400Hz Ground Power Unit (GPU) Converter and storage batteries. The PCA and GPU supplies pre-conditioned air and compatible electric power respectively to aircraft docked at an existing Passenger Boarding Bridge (PBB), or alternatively parked at a remote stand (Njeri Gitau, 2019). The airport solar power system is ground-mounted and can produce 820,000 kilowatt hours (KWh) of energy per year (Construction Review Online, 2018; Giasson, 2018). The system occupies a site of around 1.5 acres (0.60 hectares) (Njeri Gitau, 2019). The photovoltaic (PV) solar system has been designed to prioritize the consumption of the solar power over the grid at Moi International Airport (Construction Review Online, 2018).

4.4 Environmental Benefits of Moi International Airport Photovoltaic (PV) Solar System

Moi International Airport photovoltaic (PV) solar system reduces existing emissions (including CO_2) from the aircraft on-board auxiliary power unit (APU) that is powered by jet fuel and from portable ground power units (GPU), which are powered by diesel by providing pre-conditioned air and compatible electricity powered by solar energy to aircraft during ground operations (Njeri Gitau, 2019). It has been estimated that the new solar system will reduce Moi International Airport's annual carbon dioxide (CO_2) emissions by 1,300 tons (Giasson, 2018). This solar powered gate equipment will serve more than 2,500 flights annually, and thus, will play a key role in reducing aviation related emissions at the airport (Prateek, 2018). The solar system will also have an economic benefit as it will enable the Kenya Airports Authority (KAA) to save on its electricity costs (Njeri Gitau, 2019).

V. CONCLUSION

Airports play a vital role in the air transport industry value chain by facilitating passenger mobility and the transportation of time sensitive air cargo consignments. However, harmful carbon dioxide (CO_2) emissions are a major by-product of airport operations, and these carbon dioxide (CO_2) emissions can have an adverse impact upon the environment. Large amounts of energy are also used to power airport buildings and the airfield infrastructure. Considering the environmental impact of their operations, airports around the world are increasingly adopting the use of renewable energy technologies to reduce their carbon footprint. The use of renewable energy sources delivers important environmental and financial benefits to the airports that use such systems. Based on an in-depth instrumental case study research design, this study has examined the photovoltaic (PV) solar system installed at Moi International Airport in Kenya.

The case study revealed that Moi International Airport has built photovoltaic (PV) solar system with a 500kW capacity that is used to provide solar power at the airport's apron area. The system uses ground-based solar panels. The photovoltaic (PV) solar system has delivered Moi International Airport with important environmental related benefits. The photovoltaic (PV) solar system has enabled the airport to reduce it carbon footprint, as the system has reduced the airport's carbon dioxide (CO_2) emissions by an estimated 1,300 tonnes per annum. There has been a financial benefit as well, as the airport has been able to reduce its electricity costs. The case study also revealed that this is a very innovative solution as it provides an excellent way to reduce the aircraft auxiliary power unit (APU) emissions during the aircraft turnaround process at the airport.

A limitation of the present study was that actual annual energy data produced by the airport's photovoltaic (PV) solar system was not readily available.

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