Journal of the Ghana Institution of Engineering (2024) 24:3
https//doi.org/10.56049/jghie.v24i3.195

ORIGINAL RESEARCH (Presented at 2024 GhIE Annual Conference & AGM)

Ghana's electric vehicle policy: a path to aviation industry decarbonisation

God'sable S. K. Aidam [1,2,3,*], Eunice A. Adjei [1,2], Richard Opoku[1,2], David K. Oppong[1], William G. Agyare[4]

Received: 15th February, 2024 / **Accepted:** 28th September, 2024
Published online: 5th December, 2024

Abstract
The global rise in carbon dioxide emissions from transportation, particularly post-pandemic, has amplified the urgency for decarbonising sectors like aviation, which contributes around 3 % of human-induced CO2 emissions. This study reviews the transformative potential of electric vehicle (EV) adoption in Ghana's aviation industry, particularly focusing on ground operations. By leveraging Ghana's National Electric Vehicle Policy, which aligns with global sustainable energy strategies, the paper examines the country's unique position in advancing decarbonisation efforts in aviation. The study draws from global case studies, assessing the feasibility and benefits of integrating EV technologies into aviation, and presents Ghana's rich lithium resources as a strategic asset. The paper proposes targeted policy and infrastructure development as pathways to align Ghana's aviation with international decarbonisation goals. The novelty of this study lies in its comprehensive analysis of the intersection between EV policies and aviation decarbonisation in Sub-Saharan Africa, which can position Ghana as a leader in this transition.

Keywords: Electric Vehicles, Aviation Decarbonization, Sustainable Transportation, Electric Aviation Technologies

Introduction
According to the International Energy Agency (IEA), global carbon dioxide (CO2) emissions from the transportation sector experienced a growth of over 250 million tons (Mt CO2) in 2022, reaching close to 8 gigatons (Gt CO2), marking a 3 % rise from 2021. This uptick is attributed to the resurgence in passenger and cargo transport activities post the coronavirus (COVID-19) pandemic, resulting in a 3 % increase in CO_2 emissions from transportation compared to the preceding year. From 1990 to 2022, transport emissions exhibited an annual average growth rate of 1.7 %, surpassing all other end-use sectors except for industry, which also recorded a growth rate of around 1.7 %. The aviation sector played a significant role in this increase, particularly due to the recovery of air travel from pandemic-induced lows, reaching approximately 70 % of 2019 levels. Despite this, the transportation sector still heavily relies on oil products for almost 91 % of its final energy.

The global transportation sector accounts for a significant portion of energy consumption, with passenger transport playing a major role, particularly in Africa, where the sector's energy use is projected to increase substantially. As global mobility demand rises with economic growth, aviation contributes about 3 % to global human-induced CO_2 emissions (ICAO, 2019). With African economies growing faster, leading to a 5 % annual growth in air traffic, environmental concerns are gaining attention (U.S.Energy Information Administration, 2016). The aviation industry, contributing 12 % of greenhouse gas emissions in global transportation, aims to adopt sustainable fuels like hydrogen and bio-jet fuel to align with emission reduction goals (IATA, 2015; Han, Yu and Kim, 2019). The International Civil Aviation Organization (ICAO) established goals in 2010 to enhance fuel efficiency and maintain carbon emissions, relying on strategies such as alternative fuels and improved technology. Worldwide, airports are embracing renewable energy, and some airlines are exploring biofuel blends. However, such initiatives face challenges in Africa, where biofuel availability remains limited due to feedstock and technology constraints.

*Corresponding author: aidamkoku@yahoo.com

[1]Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[2]Sustainable Energy Service Center, KNUST, Kumasi, Ghana

[3]Aerojet Aviation, Accra, Ghana

[4]Ghana Civil Aviation Authority, Accra, Ghana

Nonetheless, studies have shown that electric propulsion is advantageous over conventional propulsion systems as it does not generate emissions as well as responds faster and is less noisy (Wheeler *et al.*, 2021). Electrifying transportation, when executed properly, holds substantial benefits for public health, the environment, the economy, and grid management. Electric vehicles (EVs) are three times more efficient than internal combustion engine (ICE) vehicles, converting 60 % of grid energy into miles travelled, compared to the 20 % efficiency of comparable ICE vehicles (Glitman *et al., 2019)*. This efficiency has significant implications for decarbonising the economy. The electrification of road transport in the form of hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs), battery electric vehicles (BEVs), and fuel-cell electric vehicles (FCEVs) has seen significant progress, driven by supportive policies. Initially focused on demand-side subsidies, policies have evolved to include supply-side mandates and various incentives to advance EV battery value chains (IEA, 2023).

EV technologies have also been integrated into aviation. Electric propulsion systems are employed in electric aircraft, ranging from small drones to urban air mobility vehicles and regional planes. Additionally, electric ground support equipment at airports, such as electric baggage tractors and buses, further extends the use of electric vehicles in aviation-related operations. These applications aim to revolutionise short-distance travel, improve energy efficiency, and contribute to the aviation industry's transition to cleaner technologies. These initiatives have been adopted in some developed countries; however, the ICAO's CO2 mitigation plan for the Economic Community of West African States and other African countries lacks a comprehensive approach to utilise electric vehicles, reflecting a gap in integrating aviation electrification in Africa (International Civil Aviation Organisation, 2023). This paper explores the transformative impact of adopting electric vehicles in the aviation industry, leveraging Ghana's Electric Vehicle (EV) policy to contribute to the transition of cleaner technologies in the aviation industry.

In this study, the research employs a multi-method approach to explore the potential of electric vehicle (EV) adoption within Ghana's aviation industry. The methodology includes a comprehensive review of existing literature on global EV and aviation decarbonisation practices, supported by qualitative case studies from regions with successful implementations of similar technologies. Additionally, the study analyses data from policy documents, industry reports, and stakeholder discussions to assess the feasibility of integrating EVs into Ghana's aviation sector. By conducting an

analysis of Ghana's EV policy with international practice, the research identifies key gaps and opportunities, leading to strategic recommendations for sustainable aviation practices.

State of Ghana's transportation sector and emission reduction strategies

In recent years, the registered vehicles in Ghana have significantly increased, reaching over 3.2 million in 2022 (Peprah, 2023). The sector faces a critical challenge due to the prevalence of relatively old, environmentally harmful, second-hand vehicles and a heavy reliance on fossil fuels as the sole energy source. Despite efforts like imposing higher taxes on older vehicles to control their influx, the transport sector remains a major and rapidly growing contributor to greenhouse gas emissions. Studies conducted corroborate with the Environmental Protection Agency of Ghana, which identifies vehicular exhaust emissions from road transport as the largest single contributor, accounting for 48 % of total energy emissions and 17 % of national emissions (Angnunavuri *et al.*, 2019).

In 2021, Ghana's transportation sector emitted nine metric tons of CO_2. The CO_2 emissions from transportation in Ghana experienced growth from 1 metric ton in 1972 to 9 metric tons in 2021, exhibiting an average annual growth rate of 4.97 % (Knoema, 2024). This situation is not unique to Ghana, as globally, transport contributes to 37 % of CO_2 emissions from end-use sectors. Furthermore, data reveals that transport emissions have grown at an annual average rate of 1.7 % from 1990 to 2022, surpassing the growth rate of any other end-use sector except for industry (IEA, 2023).

As a participant in international and continental agreements, including the Paris Agreement, the Accelerating to Zero Coalition (A2Z) initiative, the 2030 Agenda for Sustainable Development, and Agenda 2063: The Africa We Want, Ghana strategically positions itself to champion the adoption of green technologies. The updated nationally determined contributions (NDCs) of Ghana outline 19 policy actions across ten priority areas, aiming to achieve specific contribution goals in the next decade. By 2030, Ghana anticipates achieving a significant reduction of 64 $MtCO_2e$ in greenhouse gas emissions and preventing at least 2,900 premature deaths annually through improved air quality (Environmental Protection Agency and Ministry of Environment and Science, 2021). The transport sector is identified as one of the ten focus areas for mitigation and resilience in the NDCs. To realise this commitment, the Ghanaian government has implemented various initiatives and activities to encourage the adoption of electric vehicles. Notably, the Energy Commission of Ghana launched the Drive Electric Initiative in 2019, aiming to utilise excess generated power, which, as of May 2023, amounted to 5231 MW, to power the transportation sector efficiently, considering a system peak demand of about 3561 MW (Energy Commission, 2020).

Moreover, from 2017 to 2021, approximately 17,660 Plug-in Electric Vehicles were brought into Ghana, with 67 units categorised as heavy-duty PEVs. Battery Electric Vehicles constituted 55 %, while Plug-in Hybrid Electric Vehicles accounted for the remaining 45 %. Notably, 96 % of the BEVs were electric two- and three-wheelers. Ghana presently hosts six public charging stations, reflecting a potential market response to the escalating demand for and importation of electric vehicles in the country (Energy Commission, 2022).

Beyond the introduction of Fully-Built-Units, some local vehicle assemblers have initiated modest yet ambitious efforts in assembling Semi-Knocked-Down (SKD), Enhanced SKD, and Completely-Knocked-Down cars, along with electric two- and three-wheelers. Concurrently, private enterprises have retrofitted existing Internal Combustion Engine vehicles into fully battery-powered versions. These local initiatives align with the objectives of the Government of Ghana's automotive development policy, envisioning the country as "a fully integrated and competitive industrial hub for the Automotive Industry in the West Africa sub-region" (Ministry of Transport, 2023).

Regarding the aviation sector, Ghana is actively engaged in international initiatives to monitor, report and mitigate aviation emissions. This involvement encompasses the adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), mandating airlines to compensate for emissions exceeding a predetermined baseline. Additionally, Ghana has formulated and submitted "state action plans on CO_2 Emissions Reduction Activities from international aviation" to the International Civil Aviation Organization (ICAO). These plans function as strategic tools outlining the measures Ghana Civil Aviation Authority plans to implement within a specified timeframe to achieve targeted reductions in CO_2 emissions. Within the African sub-region, Ghana is active as a member of the African Civil Aviation Commission. This commission is dedicated to advancing initiatives that expedite the development and deployment of Sustainable Aviation Fuels (SAF), Low Carbon Aviation Fuels (LCAF), and other cleaner energy sources in the aviation sector across Africa.

Electric vehicles: Ghana's approach

Like many nations, Ghana faces challenges associated with the dominance of ICE vehicles, primarily fuelled by diesel, petrol, and Liquified Petroleum Gas. Recognising the urgent need to address environmental and health impacts, Ghana formulated the National Electric Vehicle Policy, a transformative initiative seeking to revolutionise the country's transportation landscape. This section discusses a brief review of Ghana's electric vehicle policy.

The policy responds to critical issues in the transport sector, both globally and locally. The sector, identified as a major contributor to greenhouse gas emissions, poses significant environmental costs. Fossil fuel combustion in vehicles is a major source of air pollution, leading to global health concerns and millions of premature deaths. Additionally, the policy acknowledges the role of ICE vehicles in contributing to noise pollution and affecting urban well-being, and it recognises the environmental risks posed by fuel spills and leaks.

The overarching vision of the policy is to foster the sustainable adoption of safe and affordable Electric Vehicles (EVs), aiming to reduce emissions and enhance citizen well-being. This vision aligns with Ghana's commitment to a reliable electricity supply, as emphasised in the National Energy Transition Framework (2022-2070), dedicated to decarbonising the energy sector. The ultimate goal is to create an enabling environment for EV uptake through stakeholder consultations, addressing barriers to adoption harmoniously with Ghana's overarching vision. The policy outlines eight strategic objectives, encompassing the promotion of sustainable demand, support for the EV supply chain, establishing Ghana as a lithium-ion battery hub, ensuring adequate electricity supply for EV charging, and developing human capital for the EV value chain. These objectives form a comprehensive framework to drive the sustainable evolution of the electric vehicle ecosystem.

The policy was guided by principles of health and safety, equity, circular economy, and inclusivity; the policy addresses concerns around EV safety, promotes fairness, encourages circular economy practices, and ensures an inclusive transition that benefits all segments of society. The implementation of the policy is to be coordinated by a specialised Climate Change Unit within the Ministry of Transport, collaborating with an Inter-Ministerial Committee. This dedicated structure aims to oversee the effective and successful implementation of the policy, ensuring a coordinated and strategic approach.

The policy unfolds across three distinct phases: the

preparatory phase (2024-2026) focuses on addressing challenges and laying the groundwork. The transition phase (2027-2035) targets a 35 % EV penetration rate, marking a significant shift. The advancement phase (2036-2045) aims to halt new petrol or diesel vehicle sales or imports by 2045, signalling a transformative milestone in Ghana's commitment to sustainable transportation.

In conclusion, Ghana's national electric vehicle policy emerges as a forward-thinking and holistic strategy, addressing environmental, health, and economic challenges associated with traditional vehicle technologies. Through this comprehensive and phased approach, Ghana's national electric vehicle policy aimed to drive a sustainable shift in the country's transportation landscape, promoting environmental responsibility and citizen well-being.

Electric vehicles in aviation

One of the most promising contributors to the attainment of an environmentally clean aviation industry is the transition to electric propulsion, explored under aircraft-related technology development. Several innovations have, therefore, been developed to reduce carbon emissions. The concept of electric propulsion has been in existence for a long time, with the glider MB-E1 recorded as the first manned electric aircraft, tested in 1973, about 70 years after the world's first fully controlled test flight (Wheeler *et al.*, 2021). Studies have shown that electric propulsion is advantageous over conventional propulsion systems as it does not generate emissions during flight, responds faster and is less noisy. However, at present, commercial aircraft are solely operated on fossil fuels due to the high energy density and well-developed internal combustion engines, with the expectation that the current technologies will be supported by more sustainable fuels such as hydrogen, electricity and liquid biofuel in years to come to achieve the global aspiration of reduced greenhouse gas emission (International Air Transport Association, 2015; Han, Yu and Kim, 2019). Despite the high theoretical efficiencies recorded for the various electric propulsion systems, the major limitation to their implementation is the gravitational specific energy and energy density of batteries and hydrogen aside from regulatory challenges, which are seen as the main enablers for electric propulsion.

Notwithstanding the current challenges, the potential environmental and economic benefits of electric propulsion have given birth to feasible electrical propulsion concepts that have the potential to reduce carbon emissions in the short to medium term, such as more electric or hybrid electric propulsion systems. Also, to achieve a feasible clean aviation industry in the near future, the NASA N+3 programme proposed a transition from chemical combustion energy to electrochemical energy through hybrid energy systems (Sehra and Whitlow Jr, 2004).

Aircraft electric propulsion systems are usually described based on the level of hybridisation of the power plant which is the combination of different energy sources to provide aircraft propulsive power. Based on the topology of the power train, including the battery energy and motor power, electric aircraft architectures can be defined as all-electric, hybrid-electric propulsion (HEP) or turboelectric aircraft (Brelje and Martins, 2019). All electric aircraft, as the name depicts, are fully powered by batteries or fuel cells, while turbo-electric and hybrid electric combine various electric power sources with conventional engines. Hence, turbo-electric aircraft are sometimes referred to as hybrid electric aircraft without batteries for energy storage.

Hybrid electric propulsion systems consist of an integrated conventional combustion engine and electric powertrain for propulsion. This combination of one or more power sources can be configured in series or parallel to the conventional engines. This combines the clean power of an electric propulsion system and the extended range of conventional combustion engines. Hence, there is less fuel burn and low greenhouse gas and noise emissions in comparison to conventional aircraft, and increased range and endurance compared to an all-electric aircraft (Xie *et al.*, 2021). Despite the advantages, hybrid propulsion systems are limited in application due to the cost of increased complexity and energy management. As a result, there has been growing interest in hybrid propulsion and its application in aviation.

To reduce pollution in airport operations, the aviation industry has implemented electric vehicles and equipment within GSE operations. This initiative has significantly influenced the reduction of pollution levels that have historically been associated with this sector. Ground support equipment (GSE) encompasses the equipment utilised at airports, involving the use of ground vehicles and machinery for various ground handling services. These services range from the arrival to the departure of a passenger aircraft, covering activities such as cargo and passenger loading, as well as ensuring the mobility of aircraft. Firefighting, de-icing aeroplanes, loading food, removing sewage, loading potable water, transporting passengers, loading luggage/freight, towing aeroplanes or luggage/freight carts, and refuelling are among the services provided. Electric vehicles include water and lavatory trucks, pushbacks, luggage tugs, belts, and container loaders (NREL, 2017).

GSE holds significant potential for electrification due to its suitability for applications with low-end torque, idle periods, frequent starts/stops, and short ranges. Electric power sources can efficiently meet various auxiliary loads, such as hydraulic lifts for equipment accessing high aeroplanes, refrigeration for catering, and pumps for fuel, potable water, and sewage, in contrast to idling diesel-powered vehicles. Some operators prefer electric GSE because of several features, which include an "inching device" enabling precise manoeuvres and the ability to place electric chargers in more airport locations, reducing GSE traffic and non-productive travel (NREL, 2017).

Global case: aviation decarbonisation through EVs

In exploring the impact of Electric Vehicle policies on aviation decarbonisation, it is insightful to examine case studies from around the world where innovative strategies have effectively reduced carbon emissions in the aviation sector. These success stories serve as benchmarks for understanding the tangible benefits and outcomes achievable through implementing robust EV policies. Airports have incorporated electric Ground Support Equipment (eGSE) since the initiation of the first major project led by American Airlines at El Paso International Airport in 2001. A 2013 survey from ground support worldwide revealed that 10 % of the existing GSE was electric. The Federal Aviation Administration's Voluntary Airport Low Emissions Program and Inherently Low-Emission Airport Vehicle Program often funded various eGSE deployments. As of May 2016, the National Renewable Energy Laboratory identified at least 22 U.S. airports with notable eGSE initiatives, with major projects at Sea-Tac, Philadelphia, and Dallas, Fort Worth, each utilising between 230 and 430 eGSE. Delta Airlines reported a conversion of 15 % (equivalent to 15,000 pieces) of its GSE fleet to eGSE by early 2016 (NREL, 2017).

According to (Fortune Business Insights, 2023) the global ground support equipment market was valued at USD 7.14 billion in 2022 and is expected to grow from USD 8.34 billion in 2023 to USD 13.32 billion by 2031, with a projected CAGR of 6.03 % during the forecast period. North America dominated the market in 2022, valued at USD 2.30 billion, driven by the thriving aviation industry, increased R&D investments in aviation GSE, and the presence of numerous airports and airlines, particularly in the U.S. Asia Pacific is anticipated to experience the highest growth from 2023 to 2031, attributed to rising investments in the aviation sector by emerging

economies like India and China. Europe is expected to show significant growth due to increased air travel and augmented spending on aviation by regulatory authorities in countries like the U.K., France, and Germany. The rest of the world market is set for remarkable growth from 2023 to 2031, fuelled by the rapid expansion of the aviation sector and increased air traffic in Middle Eastern countries such as the UAE, Saudi Arabia, Israel, and Turkey.

In the United States, Delta Air Lines is making strides towards its sustainability goals by transitioning key hubs, such as Salt Lake City and Boston, to predominantly electric ground support equipment (GSE). GSE, including baggage tractors and catering trucks, is being almost entirely replaced with electricity-powered vehicles at these airports. Delta aims to achieve 50 % electrified GSE at five hubs by 2025, 100 % electrified GSE at all Delta hubs with renewable energy powering operations by 2035, and ultimately net-zero operations by 2050. The airline's $385 million investment in electrified GSE and airport infrastructure is part of a four-year project (2020-2024) to enhance sustainability across its operations. Delta sees this transition as contributing to improved air quality, reduced hazardous waste, and lower noise pollution at airports (Jack, 2023).

In the UK, Loganair, the UK's largest regional airline, has completed its first all-electric aircraft turnaround as part of its efforts to decarbonise ground operations. This accomplishment is a result of a £2 million investment in ground handling technology, including electric baggage tractors, luggage belts, solar-powered boarding ramps, and hybrid ground power units. Upon full integration, this initiative is expected to eliminate the need for over 70,000 litres of diesel annually in Loganair's ground operations in the Highlands and Islands (May, 2023a).

In Hungary, Wizz Air has achieved a significant milestone by fully electrifying its ground handling operations at Budapest Airport, becoming the first airline to do so. The airline is dedicated to further reducing its carbon footprint by an additional 25 % by 2030. Budapest Airport has already achieved a remarkable 65 % reduction in operational emissions over the past decade and currently supports over 100 electric ground support vehicles with 43 charging car parks (Today, 2023).

The Indian Civil Aviation Ministry has adopted standardised ground-handling equipment, permitting the use of electric vehicles at airports to reduce carbon emissions and lower transportation costs. Presently, 403 electric vehicles are operational across 26 airports in India (Indian Times, 2022).

In the African context, Menzies Aviation has invested 3.6 billion UGX (995 million USD) to replace diesel ground handling equipment with electric alternatives at Entebbe Airport (EBB) in Uganda. This initiative enhances safety, sustainability, and complies with the Uganda Civil Aviation Authority's mandate for a digital system to manage ground services. The new electric equipment includes an ambulance, a COBUS apron bus, and forklifts, contributing to improved efficiency in cargo handling (May, 2023b).

Surf Air Mobility (SAM) has secured deals with Kenyan operators Safarilink and Yellow Wings to provide its electric or hybrid-electric powertrains for retrofitting Cessna Grand Caravans. The company's objective is to establish sustainable, short-haul direct air services between airports using electrified aircraft. After FAA certification is expected in 2026, both Safarilink and Yellow Wings plan to adopt SAM's proprietary powertrain and achieve an all-electric fleet by 2027. Safarilink, which currently operates a fleet of 12 aircraft, aims to serve over 500 airfields in East Africa with more than 30 flights daily to 18 destinations (Daleo, 2024). At Swissport Nairobi's Cargo warehouse, all ground support equipment is electric, and the cargo warehouse's roof is equipped with solar panels, producing around 30 % of the necessary energy, with anticipated increases in the future (Aviation Pros, 2022).

Several countries have taken significant strides in promoting electric aviation. In Ghana, Swissport, Menzies and Aviance, which are major ground handling and cargo companies at the airport, have equally shown the potential of decarbonization through the integration of electric vehicles in their operations. The EV policy, therefore, serves as the learning platform for the adoption of such innovations in Ghana airports. These case studies underscore the transformative power of EV policies in achieving aviation decarbonisation. Whether through the electrification of regional flights, ground support operations, air taxis, or comprehensive sustainability measures at airports, these global examples provide valuable insights into the diverse strategies that can be employed to create a more sustainable and environmentally friendly aviation sector.

Ghana's EV policy impact on aviation decarbonisation

Ghana's National Electric Vehicle (EV) Policy extends its transformative potential beyond ground transportation, significantly impacting the aviation sector and aligning with global goals for decarbonisation. The direct (Figure 1) of Ghana's EV policy on aviation underscores a commitment to sustainable practices and offers a roadmap for the industry's cleaner, greener future.

Ghana's national electric vehicle policy extends its positive impacts to the aviation sector, offering a holistic approach to sustainable transportation. The direct reductions in ground emissions, infrastructure synergies, and the promotion of sustainable energy practices present tangible benefits. Furthermore, the indirect impacts, such as global leadership, policy synergies, and technology collaboration, position Ghana as a frontrunner in shaping a greener and more sustainable future for aviation.

Leveraging Ghana's EV policy for aviation industry decarbonisation

Ghana's visionary national electric vehicle policy offers a unique opportunity to not only revolutionise ground transportation but also to act as a catalyst for the decarbonisation of the aviation industry. This section discusses strategic avenues, collaborations, and infrastructural advancements that can be leveraged to seamlessly integrate EVs into aviation operations, aligning with global efforts to reduce the carbon footprint of air travel.

The global transportation sector is responsible for a significant portion of greenhouse gas emissions, with the aviation industry being a major contributor. As countries strive to combat climate change and reduce carbon footprints, the adoption of electric vehicles has emerged as a promising solution. The aviation industry stands at the crossroads of an unprecedented challenge and opportunity - the urgent need to curb carbon emissions while continuing to meet the demands of global travel. Ghana's EV policy presents a transformative pathway for the aviation sector to significantly decarbonise and embrace sustainable practices. Leveraging electric vehicles within Ghana’s aviation industry marks a pivotal step toward reducing its carbon footprint and steering it towards a greener future. Following the technological maturity of EVs compared to other carbon reduction measures in the aviation industry, EVs present a feasibly immediate solution to aviation decarbonization in Ghana.

Electric vehicles have emerged as a promising solution across various transportation sectors, and their integration into aviation operations presents a unique prospect. While the direct electrification of aircraft remains a considerable challenge due to technological limitations, leveraging EVs on the ground is a tangible starting point. Electric vehicles have gained traction in the land transportation sector due to their zero-emission capabilities and energy efficiency. The aviation industry can harness the advantages of EV technology to reduce its environmental impact and transition towards sustainable practices. EVs offer several benefits to the aviation sector, including reduced carbon emissions, improved air quality, and decreased noise pollution.

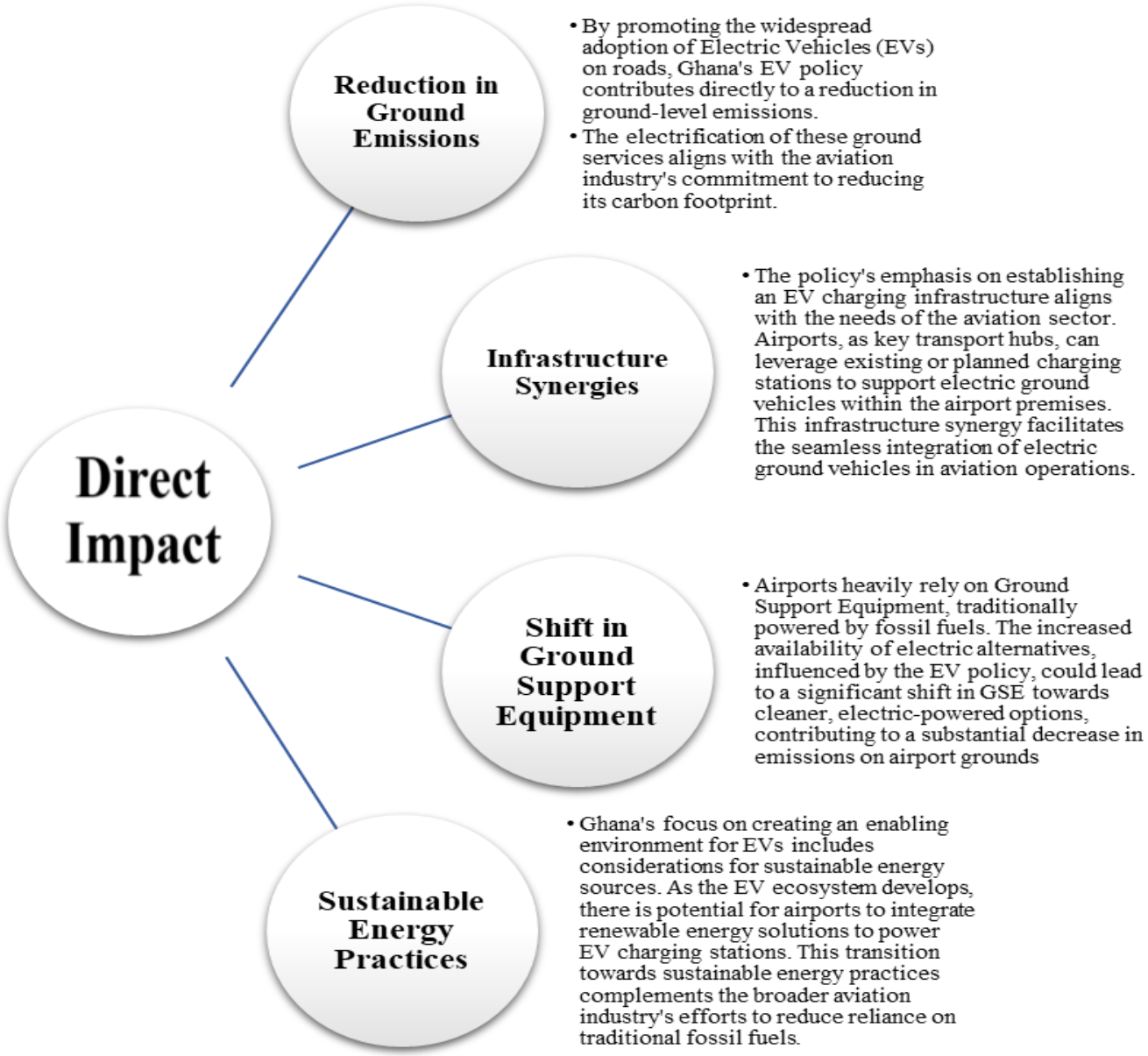

Figure 1 Direct impacts indirect impacts of Ghana's EV policy on aviation decarbonisation

Airports rely heavily on a range of ground vehicles for various operations, such as baggage handling, aircraft towing, and maintenance. Ground support equipment, including baggage tugs, aircraft tractors, and ground power units, plays a pivotal role in airport operations. Transitioning these vehicles from traditional fossil fuel-powered engines to electric alternatives aligns with Ghana's EV policy objectives and sets the stage for a more sustainable aviation ecosystem. By introducing electric GSEs, airports in Ghana can substantially cut down emissions generated during ground operations, contributing significantly to the industry's decarbonisation. Several airports worldwide have already implemented electric GSE fleets. For instance, Amsterdam Airport Schiphol has deployed electric vehicles for ground operations, significantly reducing emissions and noise levels (Ground Handling International, 2023). Moreover, the EV policy's emphasis on promoting sustainable demand for electric vehicles can extend to incentivising airlines and aviation-related businesses to adopt electric or hybrid vehicles for their logistical operations. Encouraging the use of electric vans or trucks for cargo transportation to and from airports can further reduce the sector's reliance on fossil fuels.

Charging infrastructure development stands as another critical aspect of leveraging EVs in the aviation sector. Investing in charging stations within airport premises enables efficient charging of electric vehicles used for ground operations. This infrastructure should be strategically positioned to support seamless operations without compromising service efficiency or causing disruptions. The successful integration of EVs into the aviation industry requires a robust charging infrastructure and advancements in battery technology. Establishing a network of charging stations at airports and implementing fast-charging solutions are imperative for supporting the adoption of electric aviation. Additionally, advancements in battery technology, such as increased energy density and extended range, are essential for enabling long-haul electric flights.

The opportunities for Ghana to adopt electric vehicles at the airport lie in the integration of efficient charging systems and the exploration of novel concepts such as Aviation-to-Grid (A2G). Previous studies that addressed the stochastic charging needs of electrified air transport, proposed optimal airport charging infrastructure, and presented strategies for EA battery swaps and recharging (Doctor *et al.*, 2022; Bao *et al.*, 2023). There is potential for Ghana to benefit from insights on smart charging systems for heavy electric vehicles, achieving cost reductions and considering different charging strategies such as plug-in charging and battery swap (Justin *et al.*, 2020). However, the current research gap in understanding the interactions between EV charging systems and airport energy systems provides an opportunity for comprehensive evaluations and strategic planning in the adoption of EVs at airports.

Additionally, leveraging Vehicle-to-Grid (V2G) technology, as explored in various studies, could offer benefits in terms of optimising energy systems, reducing costs, and improving overall operational efficiency (Guo *et al.*, 2023).

Collaboration between governmental bodies, aviation authorities, private enterprises, and vehicle manufacturers becomes imperative for the successful integration of electric vehicles into the aviation industry. Public-private partnerships can foster innovation, drive investment in EV technology, and streamline the adoption process, aligning with Ghana's vision for a sustainable transport ecosystem.

Education and training also emerge as pivotal elements in this transition. Building human capacity and expertise in operating, maintaining, and managing electric vehicles within the aviation sector ensures a smooth and effective adoption process. This approach facilitates a gradual shift towards cleaner technologies, ensuring the workforce is equipped with the necessary skills to navigate this transformative phase.

Furthermore, Ghana holds a significant advantage in the adoption of EVs within the aviation industry, primarily due to the discovery of rich lithium deposits. These deposits, found in the Central, Western, and Volta regions in commercial quantities, are crucial for the production of lithium-ion batteries, which are essential components of electric vehicles. Recognising this strategic opportunity, Ghana has approved a new Green Minerals Policy, amending the Mining and Minerals Policy of 2014. The updated policy establishes progressive regimes to effectively manage the exploitation and production of lithium, positioning the country as a potential hub for lithium-ion battery manufacturing. As part of this initiative, the government has granted a fifteen-year Mining Lease to Barari DV Ghana Limited, a subsidiary of Atlantic Lithium Limited, for the construction and mining of lithium at Ewoyaa in the Central Region (Ministry of Transport, 2023). The terms of the lease aim to ensure optimal benefits for the country from this valuable mineral resource. Ghana's proactive steps in lithium exploitation not only support the EV policy but also pave the way for domestic production of essential components, strengthening its position in the global shift towards sustainable aviation practices.

The transition to electric ground support equipment in aviation operations, including airports and airlines, has proven to be advantageous in terms of cost savings and environmental impact reduction. This shift is particularly prominent in towing aircraft, where electric GSE offers operational efficiency and a substantial decrease in carbon footprint. To facilitate a smooth transition, the following key steps in Figure 2 can be considered.

Challenges to overcome in implementing Ghana's EV policy

The successful adaptation of electric vehicles in Ghana is fraught with several challenges ranging from social, economic and technological issues (Energy Commission, 2022). There exists a significant awareness gap regarding electric vehicles in Ghana, as evidenced by challenges faced by individuals and companies in understanding EV-related processes such as import clearance. The need for educational initiatives, as demonstrated by the Energy Commission's Drive Electric Initiative, is crucial to bridge this gap.

The perceived high initial cost of EVs and concerns about battery replacement hinder widespread adoption. Despite the global decrease in EV prices, the perception of high costs persists in Ghana. Government incentives, similar to those implemented in other countries, could play a pivotal role in making EVs more economically competitive and attractive.

The current lifespan of EV batteries, ranging from 10 to 12 years, poses a challenge to adoption, as consumers may be hesitant about the prospect of replacing batteries. The development of the second-life battery market is not yet active in Ghana, and advancements in battery technology are crucial to improving the lifespan and overall attractiveness of EVs.

The absence of government incentives for EV users in Ghana, such as tax credits or exemptions, contributes to the high initial cost burden. Proposals for full import duty

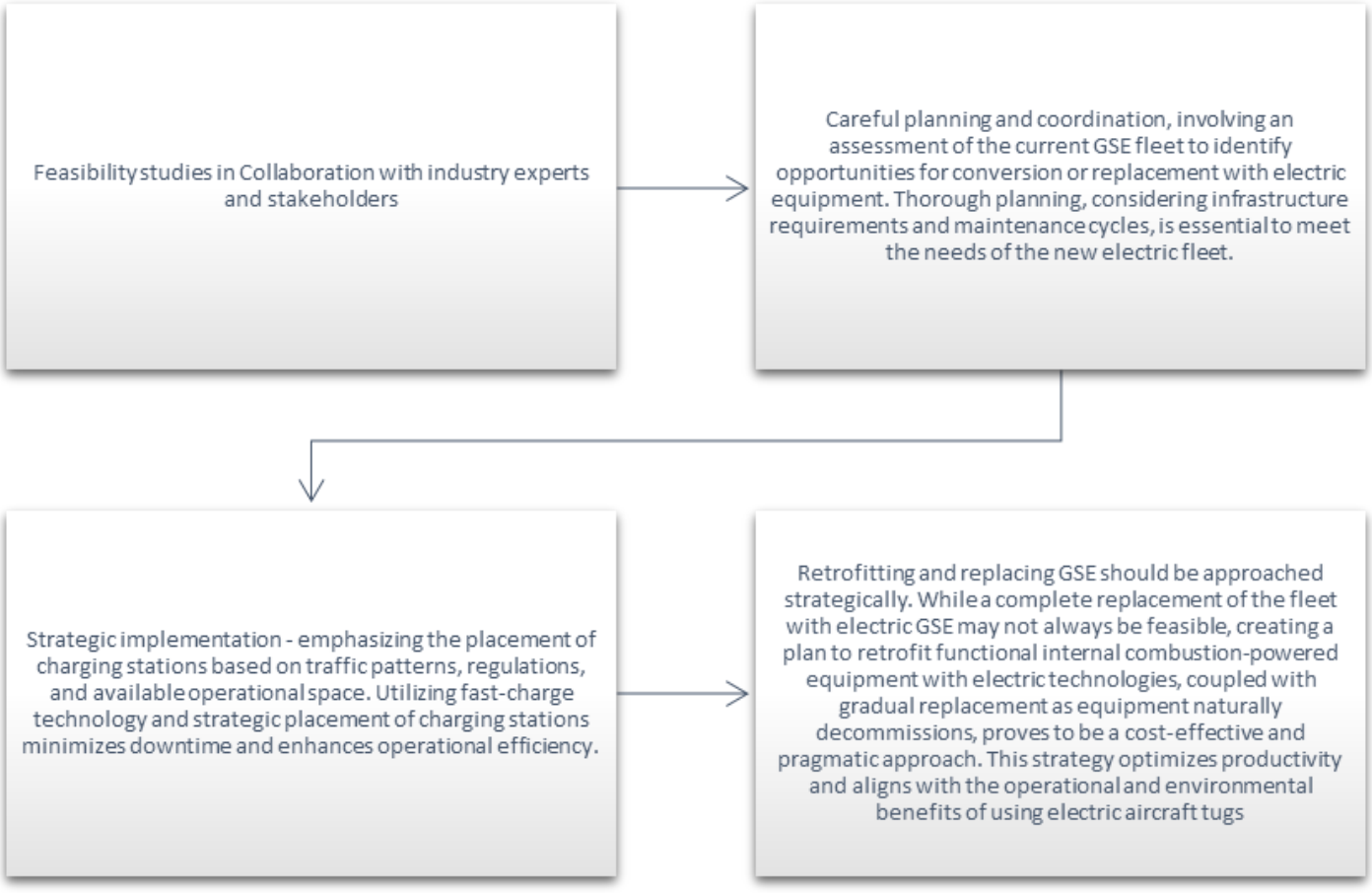

Figure 2 Transitioning to electric Ground Support Equipment (Tugs, 2023)

exemptions for Battery Electric Vehicles, tax exemptions, and non-monetary incentives like free DVLA registration and toll-free highway charges are under consideration, mirroring successful incentive models from other countries.

The availability of a robust charging infrastructure is identified as critical for successful EV penetration. While home charging is preferred, long-distance travel necessitates a widespread network of charging stations. The Energy Commission's Drive Electric Initiative is actively working on standards, regulations, and collaboration with private sector entities to promote charging infrastructure development across Ghana.

Long charging times and extra load on the national grid underscore the need for distributed power generation, such as renewable energy mini-grids on-site (Adu-Poku *et al.*, 2023; Timmermans, 2023).

Addressing these challenges with adaptive strategies will be essential in realising the full potential of Ghana's EV policy for aviation decarbonisation. By fostering collaboration, innovation, and awareness, Ghana can overcome these obstacles and position itself as a proponent of sustainable and eco-friendly aviation practices.

Conclusion

This study underscores the critical role that Ghana's National Electric Vehicle Policy can play in the decarbonisation of the aviation industry. Through strategic investments in infrastructure, electric ground support equipment, and the establishment of EV charging networks, Ghana is well-positioned to align with global trends towards sustainable aviation. The country's significant lithium resources provide further potential to develop local battery production capabilities, adding value to both domestic and international decarbonisation efforts.

The findings of this study contribute to existing knowledge by presenting a model for integrating EV technology into aviation operations within developing countries, particularly in Africa. It highlights the importance of collaboration between government and private stakeholders, recommending further research into long-term infrastructure development and regional partnerships to optimise the implementation of EVs in aviation. As Ghana aims to meet its emissions reduction targets, this research advocates for a phased approach to EV adoption, which could set a precedent for other African nations aiming to modernise their aviation sectors sustainably.

Acknowledgement

The authors thank the KNUST Engineering Education Project (KEEP) for its continuous support in advancing engineering research and development.

Conflict of Interest Declarations

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Adu-Poku, A., Koku Aidam, G.S., Jackson, G.A., N'tsoukpoe, K.E., Kponyo, J.J., Messan, A., Ikonne, O., Kwarteng, W. and Kemausuor, F. (2023). Performance assessment and resilience of solar mini-grids for sustainable energy access in Ghana', Energy, p. 129431. Available at: https://doi.org/https://doi.org/10.1016/j.energy.2023.129431.

Angnunavuri, P.N., Kuranchie, F.A., Attiogbe, F. and Nerquaye-Tetteh, E.N. (2019). The potential of integrating vehicular emissions policy into Ghana's transport policy for sustainable urban mobility. SN Applied Sciences, 1, pp. 1–14.

Aviation Pros (2022). Swissport Kenya celebrates 25 years of Operation, Aviation Pros. Available at: https://www.aviationpros.com/ground-handling/ground-handlers-service-providers/press-release/21284313/swissport-international-ltd-swissport-kenya-celebrates-25-years-of-operation (Accessed: 12 February 2024).

Bao, D.-W., Zhou, J.-Y., Zhang, Z.-Q., Chen, Z. and Kang, D. (2023). Mixed fleet scheduling method for airport ground service vehicles under the trend of electrification. Journal of Air Transport Management, 108, p. 102379.

Brelje, B.J. and Martins, J.R.R.A. (2019). Electric, hybrid, and turboelectric fixed-wing aircraft: A review of concepts, models, and design approaches. Progress in Aerospace Sciences, 104, pp. 1–19. Available at: https://doi.org/10.1016/j.paerosci.2018.06.004.

Daleo, J. (2024). Surf air mobility signs aircraft electrification deals with 2 Kenyan operators. FLYING Magazine. Available at: https://www.flyingmag.com/surf-air-mobility-signs-aircraft-electrification-deals-with-2-kenyan-operators/ (Accessed: 12 February 2024).

Doctor, F., Budd, T., Williams, P.D., Prescott, M. and Iqbal, R. (2022). Modelling the effect of electric aircraft on airport operations and infrastructure. Technological Forecasting and Social Change, 177, p. 121553.

Energy Commission (2020). Drive electric initiative (DEI). Available at: https://www.energycom.gov.gh/efficiency/drive-electric-initiative (Accessed: 9 February 2024).

Energy Commission (2022). Ghana electric vehicles baseline survey report 2022', pp. 1–70.

Environmental Protection Agency and Ministry of Environment, Science, T. and I. (2021) Ghana updated nationally determined contribution under the Paris agreement (2020 - 2030), Environmental Protection Agency & Ministry of Environment, Science, Technology and Innovation. Available at: https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Ghana First/Ghana%27s Updated Nationally Determined Contribution to the UNFCCC_2021.pdf.

Fortune Business Insights (2023). Ground support equipment market size. Share Report [2031]. Available at: https://www.fortunebusinessinsights.com/industry-reports/ground-support-equipment-market-101823 (Accessed: 12 February 2024).

Glitman, K., Farnsworth, D. and Hildermeier, J. (2019). The role of electric vehicles in a decarbonised economy: Supporting a reliable, affordable and efficient electric system', Electricity Journal, 32(7). Available at: https://doi.org/10.1016/j.tej.2019.106623.

Ground Handling International (2023). Ground Handling - Schiphol orders electric ground equipment. Available at: https://www.groundhandlinginternational.com/content/news/schiphol-orders-electric-ground-equipment/ (Accessed: 13 February 2024).

Guo, Z., Li, B., Taylor, G. and Zhang, X. (2023). Infrastructure planning for airport microgrid integrated with electric aircraft and parking lot electric vehicles. eTransportation, 17(April), p. 100257. Available at: https://doi.org/10.1016/j.etran.2023.100257.

Han, H., Yu, J. and Kim, W. (2019). An electric airplane: Assessing the effect of travelers' perceived risk, attitude, and new product knowledge. Journal of Air Transport Management, 78, pp. 33–42.

Hungary Today (2023). First airline to offer fully electric ground handling at Budapest Airport. Available at: https://hungarytoday.hu/first-airline-to-offer-fully-electric-ground-handling-at-budapest-airport/ (Accessed: 10 February 2024).

ICAO (International Civil Aviation Organization) (2019). 2019 environmental report. Available at: https://www.icao.int/environmental-protection/Pages/envrep2019.aspx (Accessed: 1 September 2020).

IEA (2023). Transport - energy system. IEA. Available at: https://www.iea.org/energy-system/transport (Accessed: 7 February 2024).

Indian Times (2022). Aviation Ministry standardises ground-handling service equipment, allows EVs for transportation. Available at: https://auto.economictimes.indiatimes.com/news/commercial-vehicle/aviationmin-standardises-ground-handling-service-equipment-allows-evs-for-transportation/89413183 (Accessed: 10 February 2024).

International Air Transport Association (2015). IATA 2015 report on alternative fuels. Geneva, Switzerland.

International Civil Aviation Organisation (2023). State action plans - facts and figures. Available at: https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan_FactsFigures.aspx (Accessed: 26 February 2023).

Jack, B. (2023). Delta: emission-free' with electric vehicles. Aviation Source News. Available at: https://aviationsourcenews.com/airline/delta-emission-free-with-electric-vehicles/ (Accessed: 10 February 2024).

Justin, C.Y., Payan, A.P., Briceno, S.I., German, B.J. and Mavris, D.N. (2020). Power optimized battery swap and recharge strategies for electric aircraft operations. Transportation Research Part C: Emerging Technologies, 115, p. 102605.

Knoema (2024). Ghana CO_2 emissions from transport, 1970-2023. Available at: https://knoema.com/atlas/Ghana/topics/Transportation/CO2-Emissions-from-transport/CO2-emissions-from-transport (Accessed: 9 February 2024).

May, T. (2023a). Loganair completes its first all-electric aircraft turnaround. Airport Industry-News. Available at: https://airportindustry-news.com/loganair-completes-its-first-all-electric-aircraft-turnaround/ (Accessed: 10 February 2024).

May, T. (2023b). Menzies Deploys Electric Ground Handling Equipment at Entebbe Airport | Airport Industry-News. Available at: https://airportindustry-news.com/menzies-deploys-electric-ground-handling-equipment-at-entebbe-airport/ (Accessed: 12 February 2024).

Ministry of Transport, Ghana (2023) The National Electric Vehicle Policy. Available at: https://www.mot.gov.gh/files/resources/National_Electric_Vehicle_Policy.pdf (Accessed: 4 March 2024).

NREL (2017). Electric ground support equipment at airports. National Renewable Energy Laboratory [Preprint]. Available at: https://afdc.energy.gov/files/u/publication/egse_airports.pdf.

Peprah, D. (2023). 3.2 million vehicles registered in Ghana as at 2022 - Transport Minister. Ghana News Agency. Available at: https://gna.org.gh/2023/07/3-2-million-vehicles-registered-in-ghana-as-at-2022-transport-minister/ (Accessed: 9 February 2024).

Sehra, A.K. and Whitlow Jr, W. (2004). Propulsion and power for 21st century aviation. Progress in Aerospace Sciences, 40(4–5), pp. 199–235.

Timmermans, K. (2023). Electric Ground Support Equipment at Airports: The impact of implementing eGSE on the capacity and demand of GSE fleets.

Tugs, E. (2023) Guide to transitioning to electric ground support equipment for towing aircraft. Available at: https://eagletugs.com/guide-to-transitioning-to-electric-ground-support-equipment (Accessed: 10 February 2024).

U.S. Energy Information Administration (2016). International Energy Outlook 2016.

Wheeler, P., Sirimanna, T.S., Bozhko, S. and Haran, K.S. (2021) 'Electric / Hybrid-Electric Aircraft Propulsion Systems', Proceedings of the IEEE, 109(6), pp. 1115–1127.

Xie, Y., Savvarisal, A., Tsourdos, A., Zhang, D. and Gu, J. (2021) 'Review of hybrid electric powered aircraft, its conceptual design and energy management methodologies', Chinese Journal of Aeronautics, 34(4), pp. 432–450. Available at: https://doi.org/10.1016/j.cja.2020.07.017.