ALTERNATIVE RENEWABLE ENERGY FOR AIRPORTS IN UNITED ARAB EMIRATES

MOHAMED AADEL ABBAS   MOHAMED SHARIF KARIMPOUR

THIS THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF MANAGEMENT

AVIATION MANAGEMENT

CIVIL AVIATION TRAINING CENTER THAILAND

ACADEMIC YEAR 2023

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Civil Aviation Training Center Thailand joined with Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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MOHAMED AADEL ABBAS MOHAMED SHARIF KARIMPOUR: ALTERNATIVE RENEWABLE ENERGY FOR AIRPORTS IN UNITED ARAB EMIRATES
THESIS ADVISOR: WARAPORN TEMKAEW, Ph.D., PP. 69

This thesis explores into alternative renewable energy solutions for airports in the United Arab Emirates (UAE). With a focus on analysing and recommending best practices, the study navigates through various avenues within the renewable energy landscape, aiming to align with the sustainability goals of the UAE's aviation industry. In the pursuit of its objectives, the research evaluates the existing state of renewable energy adoption within the UAE's aviation sector, with particular emphasis on its airports. Factors such as environmental impact, economic feasibility, and scalability are thoroughly investigated to provide a comprehensive understanding of the challenges and opportunities associated with integrating renewable energy sources into airport operations.

The study conducts a comprehensive analysis of available technologies and their suitability for integration into airport infrastructure, aiming to provide insights into the feasibility and challenges of renewable energy implementation. SWOT analysis was then applied to assess the adoption of alternative renewable energy in airports. Additionally, a circuit simulation was used to test Piezoelectricity as an alternative renewable source. This concluded with Piezoelectricity being a viable option compared to other alternative renewable sources such as solar, wind, and hydropower. This is due to its to many benefits such as minimal environmental impact and maintenance, versatility to be implemented into various airport applications (airport runways), and its simple installation. There are some drawbacks with using piezoelectricity as an alternative renewable energy source such as the requirement of a much durable piezoelectric material that would be capable of withstanding heavy loads and optimizing the energy conversion efficiency. The findings are expected to guide stakeholders, policymakers, and industry players towards a more sustainable and environmentally conscious future for airports in the UAE.

Aviation Management
Academic Year 2023

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First and foremost, I extend my heartfelt appreciation to the Civil Aviation Training Center for offering me this invaluable opportunity, as well as to the esteemed lecturers of the Faculty of Aviation Management. Special acknowledgment goes to Dr.Thanyarat Khamproh, Dr.Attapol Moungsawad, Mr.Yongyut Lujintanon, Mr.Ananchai Thongcharoen, and Mr.Korawit Mahakunwong, whose imparted knowledge significantly contributed to both my academic and professional growth, and to the completion of this thesis. I also wish to express my sincere gratitude to Dr.Waraporn Temkaew, Director of the Aviation Science Management Division, lecturer, and my project supervisor, for her invaluable guidance and support throughout this thesis, despite her busy schedule. Her dedication and prompt assistance enabled me to remain fully focused on the research.

Lastly, but certainly not least, I extend my heartfelt thanks to my parents and friends for their unwavering support and for being the source of joy in my life.

In dedicating this thesis, I pay homage to my parents and closest friends, whose belief in me and steadfast support have been my pillars during the most challenging times.

Mohamed Aadel Abbas Mohamed Sharif Karimpour

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INTRODUCTION

1.1 BACKGROUND PROBLEM

The United Arab Emirates (UAE) is situated in the south-eastern region of the Arabian Peninsula, sharing land borders with Saudi Arabia to the southwest and Oman to the east. Additionally, it shares a maritime boundary along the Persian Gulf, connecting with Qatar and Iran.

The nation spans an area of 83,600 square kilometres and was founded as a federation of seven emirates, each operating within an elective monarchy system. The seven emirates are Abu Dhabi (country's capital), Dubai, Sharjah, Ajman, Umm Al Quwain, Ras al Khaimah, and Fujairah.

As of 2020, the UAE is home to an estimated population of 9.9 million, with Dubai emerging as the most populous emirate. It is also, among others, one of the world's leading producers of oil and natural gas, ranking sixth in oil and natural gas reserves. Additionally, it is a member of the Organization of the Petroleum Exporting Countries (OPEC). The nation's substantial oil reserves, primarily concentrated in Abu Dhabi, amount to approximately 100 billion barrels, with a collective daily oil production averaging 3.2 million barrels. *(United Arab Emirates (2023))*

Whereas in Dubai, hosts one of the world's busiest international airports, Dubai International Airport (DXB) renowned for its high passenger and cargo traffic. It serves as the primary hub for Emirates airline, handling 51% of passenger traffic and 42% of all aircraft movements. *(Dubai International Airport (2023))*

In recent times, aviation has gained prominence as a convenient mode of travel. However, it has also emerged as a significant contributor to global warming through emissions of CO_2, vapor trails, and non-CO_2 effects driven by nitrogen oxide, with the latter being particularly impactful due to its high-altitude release and limited particle dispersion. The UAE, given its strategic geographical location and promotion of tourism, has established itself as a prominent aviation hub, simultaneously contributing significantly to aviation-related pollution.

In the realm of renewable energy, the UAE secured a third-place global ranking in concentrated solar power (CSP) production in 2013. Over the past decade, the country's energy industry has undergone drastic, but remarkable changes, pioneering the adoption of more affordable and cleaner energy solutions in the GCC region. *(Solar energy - the official portal of the UAE Government (2022))*

This study will contain extensive research exploring the renewable energy developments in the UAE over the past decade while investigating the emissions of greenhouse gases (GHG) in the aviation sector and their environmental impacts during this period.

In 2017, the United Arab Emirates introduced the UAE National Energy Strategy 2050, a progressive strategy aimed to enhance and augment the share of clean and nuclear energy in the nation's energy sector. The plan is to integrate 44% of renewable energy, 38% of gas, 12% of clean coal, and 6% of nuclear energy into the energy mix. *(Gulf News. (2017))*

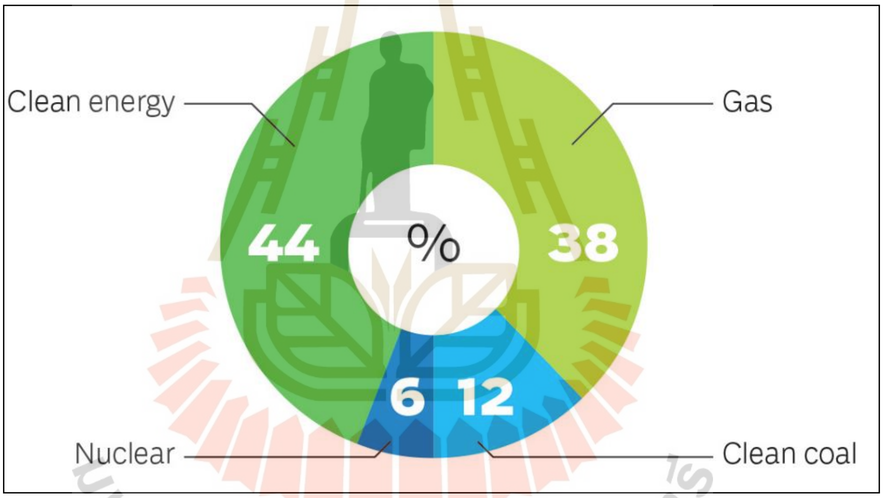

Figure 1.1 UAE (United Arab Emirates) 2050 energy goals. *(Gulf News. (2017))*

The aviation sector, in pursuit for an ever-expanding services and global connectivity, faces a significant dilemma. With the global population continuously expanding and widespread industrialization, the aviation sector is primarily reliant on energy derived from fossil fuels, resulting in a surge in greenhouse gas emissions, particularly carbon dioxide, and driving global climate change. The UAE stands among the nations with the highest per capita energy consumption worldwide, primarily driven by the burning of fossil fuels. *(Hannah Ritchie, Max Roser and Pablo Rosado (2020))*

Population and energy consumption shows a direct and interdependent relationship, where the rise in population corresponds with an increase in energy demand. Given that the UAE's demographic composition is expatriate, and tourism plays a pivotal role in the nation's economic landscape, it is anticipated that energy consumption will slowly escalate rather than decline, intensified by the prevalent climate shifts observed worldwide.

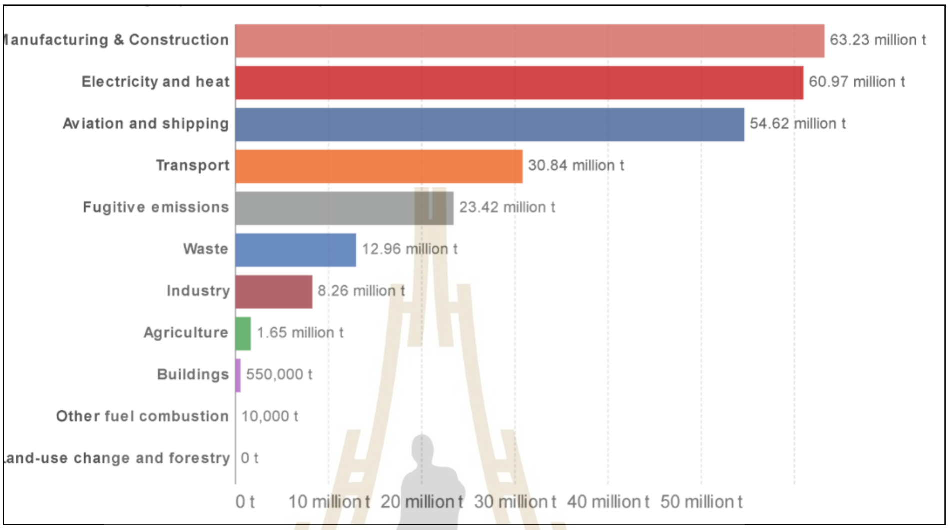

Figure 1.2 Greenhouse Gas emissions by sectors in the United Arab Emirates, 2010 *(Hannah Ritchie, Max Roser and Pablo Rosado (2020))*

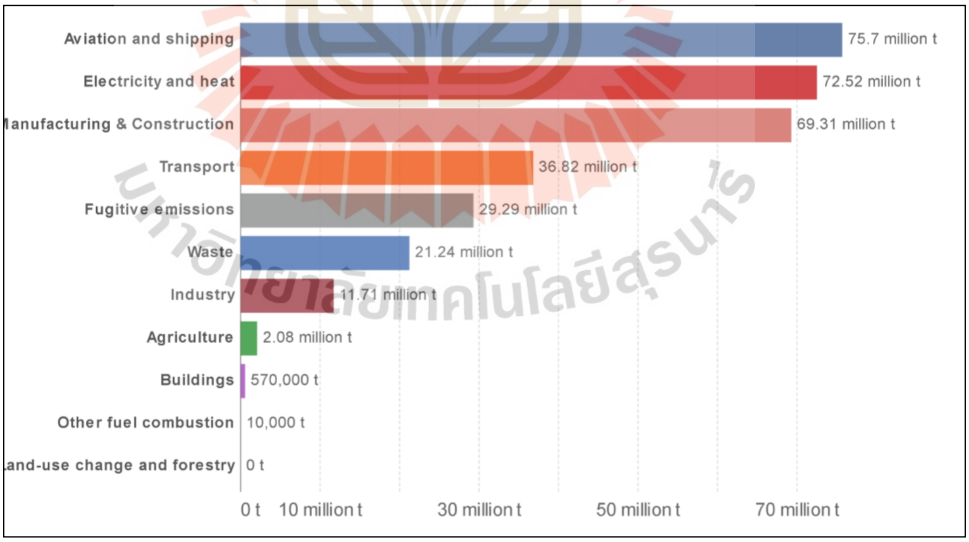

Figure 1.3 Greenhouse Gas emissions by sectors in the United Arab Emirates, 2019 *(Hannah Ritchie, Max Roser and Pablo Rosado (2020))*

This increase in energy consumption comes at a significant environmental cost. Statistics reveal that in 2010, the UAE was responsible for the emission of 2.83 billion tonnes of CO_2. By 2020, this figure had escalated to 4.9 billion tonnes, reflecting a 73% increase in emissions.

Notably, the aviation and shipping industries, which collectively contributed 1.9% (ranking third with 54.62 million tonnes) of the total CO_2 emissions in 2010, surged to 1.54% (top-ranked with 75.7 million tonnes) by 2020. These numbers underscore a substantial and concerning rise in emissions from these sectors.

In conjunction with these escalating greenhouse gas emissions, the aviation industry bears a considerable energy burden. Airports, often serving as the initial point of contact for a nation, are integral to the UAE’s global reputation. Ensuring the maintenance and operation of world-class airports demands a significant energy investment.

Given the compounded environmental impact of soaring emissions and surging energy consumption, there is an urgent need to explore alternative and sustainable approaches to mitigate energy depletion and resource exhaustion, particularly within the airports.

1.2 RESEARCH OBJECTIVE

The aim of the thesis is to explore and analyse sustainable and alternative energy solutions for airports in the UAE, with a specific focus on reducing greenhouse gas emissions by recommending the best practices.

1.3 SCOPE OF THE STUDY

1.3.1 Aviation Sector in the UAE: A comprehensive examination of the aviation sector, particularly airports, in the United Arab Emirates, including its growth, energy consumption, and environmental impact.

1.3.2 Renewable Energy Integration: Exploration of various renewable energy sources and technologies applicable to airports, such as solar, wind, piezoelectric, and other sustainable alternatives.

1.3.3 Energy Efficiency: Assessment of energy efficiency initiatives, including energy management systems, green infrastructure, and sustainable practices, within airport operations.

1.3.4 Greenhouse Gas Emissions: Analysis of the aviation sector's greenhouse gas emissions and the potential for emissions reduction through alternative energy sources and sustainable practices.

1.3.5 Environmental Impact: Investigation into the environmental consequences of airport operations, emphasizing the importance of reducing environmental footprints.

1.3.6 Technological Innovations: Examination of innovative technologies and innovations in airports, focusing on how these advancements can contribute to sustainability and energy efficiency.

1.3.7 Case Studies: Review of specific case studies and projects related to renewable energy integration and sustainability within airports in the UAE.

1.3.8 Recommendations and Solutions: Development of practical recommendations and solutions for enhancing energy efficiency, reducing emissions, and promoting sustainability in airport operations in the UAE.

1.3.9 Prospects: Exploration of potential prospects and challenges for sustainable airports in the UAE, considering emerging technologies and global trends.

The thesis project aims to provide a comprehensive understanding of the current state of the aviation industry in the UAE, with a focus on sustainable energy solutions and environmental conservation in airports.

1.4 DEFINITIONS

1.4.1 Solar Energy – Refers to radiant energy emitted by the sun, which can be harnessed and converted into usable forms of power, such as electricity or heat.

1.4.2 Wind Energy – A renewable energy source derived from the kinetic energy of moving air masses (wind). It is harnessed using wind turbines, which convert the rotational energy of turbine blades into electrical power through a generator.

1.4.3 Hydropower Energy – Also known as hydroelectric power, is electricity generated by harnessing the energy of flowing or falling water. It involves the use of dams, turbines, and generators to convert the potential energy of water into electrical energy.

1.4.4 Geothermal Energy – It is heat derived from the Earth's internal thermal energy. It is harnessed by tapping into underground reservoirs of steam or hot water and using it to generate electricity.

1.4.5 Greenhouse Gases – GHGs (greenhouse gases) are atmospheric gases that trap heat from the sun, leading to the greenhouse effect. Human activities, such as burning fossil fuels and deforestation, contribute to the increased concentration of these gases, leading to global warming and climate change.

1.4.6 Electric Circuit – An electric circuit is a closed loop or path through which electric current flows. It typically consists of electrical components such as resistors, capacitors, inductors, and conductors, connected by wires. Electric circuits can be designed for various purposes, including powering electronic devices, generating light, or performing specific functions based on the arrangement of components and the flow of electrical charge.

1.4.7 Voltage – Also known as electric potential difference, is the measure of the electric potential energy per unit charge in an electric circuit. It is expressed in volts (V) and represents the force that drives electric current through a conductor.

1.4.8 Current – It is the flow of electric charge through a conductor. It is measured in amperes (A) and represents the rate of flow of charged particles, typically electrons, in an electric circuit.

1.4.9 Capacitor – It is an electronic component that stores electrical energy in an electric circuit. When connected to a voltage source, a capacitor accumulates and stores charge, releasing it when the voltage across its terminal's changes.

1.4.10 Resistor – A resistor is an electrical component to control the flow of electric current or divide voltage in an electric circuit. It is characterized by its resistance, measured in ohms (Ω).

1.4.11 Diode – It is a semiconductor device that allows the flow of electric current in one direction while blocking it in the opposite direction.

1.4.12 SWOT analysis - a strategic planning tool used to assess and evaluate the Strengths, Weaknesses, Opportunities, and Threats of an individual, organization, project, or venture. It involves identifying internal factors (strengths and weaknesses) and external factors (opportunities and threats) to make informed decisions and develop effective strategies.

CHAPTER 2

LITERATURE REVIEW

The literature review provides a comprehensive exploration of existing knowledge and research pertaining to renewable energy applications in airports, with a particular focus on the United Arab Emirates. The review aims to provide a thorough understanding of the historical development, current state, and prospects of renewable energy integration within the aviation industry.

The chapter will cover an in-depth analysis of scholarly articles, industry reports, and governmental publications explaining the various renewable energy sources relevant to airports. Key emphasis will be placed on solar, wind, hydropower, geothermal, and bioenergy, examining their feasibility, efficiency, and potential impact on carbon footprint reduction. Additionally, expect insights into global and regional initiatives, policies, and commitments shaping the renewable energy landscape for the aviation industry.

The details of the content are as follows:

1) ICAO Policies and Practices related to sustainability in aviation
2) Aviation Greenhouse Emissions
3) Solar Energy
4) Wind Energy
5) Hydropower energy
6) Geothermal energy
7) Technical Aspects
8) Renewable energy in airports
9) Biofuel
10) Existing renewable energy in UAE
11) Renewables initiatives of UAE for aviation

2.1 ICAO POLICIES AND PRACTICES RELATED TO SUSTAINABILITY IN AVIATION

During the 41st assembly session in 2022, the International Civil Aviation Organization (ICAO) adopted Resolution A41-21, which outlines its commitment to invent policies and standards related to aircraft emissions and environmental protection. Additionally, ICAO introduced the Long-Term Global Aspirational Goal (LTAG) during the same session, aligning with the Paris Agreement's objective of achieving net-zero carbon emissions by 2050 *(ICAO. (2023))*

ICAO is actively pursuing several initiatives to foster sustainable growth in international aviation and meet its global goals. These efforts include enhancing aircraft technology, promoting sustainable aviation fuels, and implementing market-based measures such as CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). *(ICAO. (2023))*

CORSIA is a global market-based mechanism aimed at reducing emissions from international aviation, ensuring minimal market distortion while considering the unique circumstances and capabilities of ICAO Member States. It facilitates the offsetting of CO2 emissions that cannot be reduced through technological advancements or the use of sustainable aviation fuels by utilizing emissions units from carbon markets and other measures. *(ICAO. (2023))*

Sustainable Aviation Fuel (SAF) refers to aviation fuels derived from renewable or waste sources that fulfil sustainability standards. According to the LTAG report conducted by the LTAG Task Group (LTAG-TG), SAF shows promising outlook in reducing CO_2 emissions from international aviation by 2050 in support of the Paris Agreement's net-zero carbon emissions temperature goal. *(ICAO. (2023))*

ICAO employs four primary strategies to facilitate the development and deployment of Sustainable Aviation Fuel (SAF):

1) **Establishment of Globally Accepted Environmental Standards:** ICAO has devised methodologies to enable aircraft operators to reduce offsetting requirements through the utilization of SAF and Lower Carbon Aviation Fuels (LCAF) within CORSIA. These methodologies include globally accepted sustainability criteria and life cycle methodologies approved by the ICAO Council. *(ICAO. (2023))*

2) **Implementation of SAF Policies and Goals:** At the Third ICAO Conference on Aviation and Alternative Fuels (CAAF/3) held in November 2023 in Dubai, UAE, ICAO and its Member States committed to a collective effort to reduce CO_2 emissions in international aviation by 5% by 2030. This initiative involves adopting a new ICAO Global Framework for SAF, LCAF, and other Aviation Cleaner Energies, rather than solely relying on zero cleaner energy use. *(ICAO. (2023))*

3) **Capacity Building and Assistance to Member States:** ICAO has introduced the ICAO Assistance, Capacity-building, and Training for Sustainable Aviation Fuels (ACT-SAF) program. This program assists Member States through training activities, feasibility studies, and implementation support initiatives to develop their capabilities in SAF. Additionally, the ICAO ACT-SAF Series provides comprehensive monthly training sessions on various SAF-related topics for ACT-SAF Partners. *(ICAO. (2023))*

4) **Outreach of Information and Best Practices:** ICAO employs three approaches for information sharing. Firstly, through the Stocktaking Process, ICAO periodically reviews progress on SAF development and deployment, organising regular seminars. Secondly, the Sustainable Aviation Fuels Guide offers guidance to Member States on deploying sustainable aviation fuels to reduce CO_2 emissions from international aviation activities, covering usage constraints, production pathways, environmental benefits, and policy perspectives. Finally, the ICAO Global Framework for Aviation and Alternative Fuels (GFAAF) serves as an online database for sharing information related to sustainable aviation fuels, containing news articles, facts and figures, details of past and ongoing initiatives, frequently asked questions, and additional resources, including a live feed of aircraft using sustainable aviation fuels. *(ICAO. (2023))*

ICAO published an endorsed council document known as the CORSIA Eligibility Framework and Requirements for Sustainability Certification Schemes (SCS). This document, referenced in Annex 16, Environmental Protection, Volume IV, CORSIA, is crucial for CORSIA's implementation. Utilizing the agreed-upon methodology, SCS enables organisations to certify economic operators based on sustainability criteria and verify the calculation of actual life cycle emissions values. The SCS describes sustainability certification standards by establishing requirements for certification bodies, auditors, and accreditation bodies, and overseeing the assurance system's efficacy. *(ICAO. (2023))*

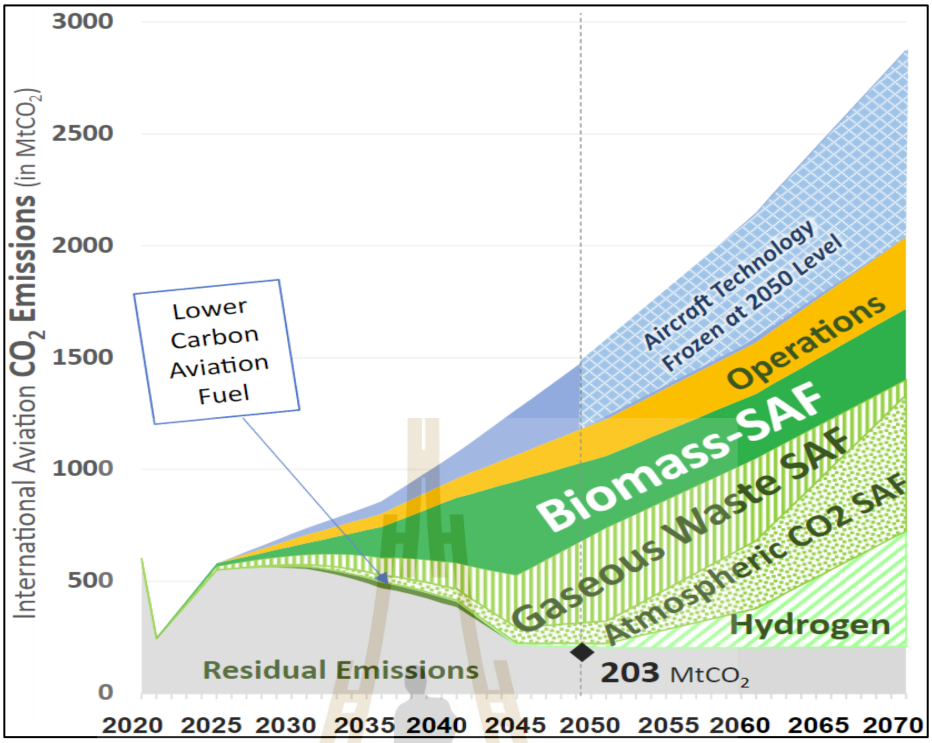

Figure 2.1 Graph of LTAG for reduction in carbon emission. *(ICAO. (2023))*

In 2016, the UAE voluntarily joined the CORSIA's pilot phase, representing a significant global emission alongside other major aviation states. Subsequently, from 2017 to 2018, the UAE initiated small-scale CORSIA projects involving two reputable airlines, Flydubai (Dubai) and Air Arabia (Sharjah), aimed at developing necessary processes, procedures, and understanding of CORSIA requirements. In 2019, workshops were conducted to prepare operators for CORSIA readiness, with nine operators, including major carriers like Etihad (Abu Dhabi), Emirates (Dubai), Flydubai (Dubai), and Air Arabia (Sharjah), participating. The key outcomes included ensuring operator compliance and readiness for CORSIA, facilitating knowledge sharing and experience exchange among operators in the UAE, and demonstrating the country's commitment to CORSIA implementation. *(ICAO. (2022))*

2.2 AVIATION GREENHOUSE EMISSIONS

The issue of aviation as remained a contentious subject in discussions about climate change, and this controversy persists for two primary reasons.

The first rationale pertains to the detachment of air travel from our personal and collective carbon emissions. In this time and age, air travel plays a vital role around climate change, primarily due to the emissions generated by frequent travellers. Despite aviation's global contribution of only 2.5% of carbon dioxide (CO_2) emissions, there is a distinct disparity in how many individuals have the means or inclination to fly. Consequently, a substantial portion of the population either cannot afford air travel or chooses not to embark on all together. *(Hannah Ritchie (2020))*

The second rationale relates to how carbon emissions from aviation are attributed to countries. Carbon Dioxide emissions from domestic flights are categorized separately as "bunker fuel" emissions and are not considered part of a country's emissions profile. Bunker fuels represent the emissions associated with international aviation and maritime transport. (Hannah Ritchie (2020))

In terms of global CO_2 emissions, aviation accounts for approximately 2.5%. While some aircraft incorporate biofuels as part of their power source, these eventually result in CO_2 emissions when burned, akin to traditional jet fuel, which remains the primary fuel source for most flights.

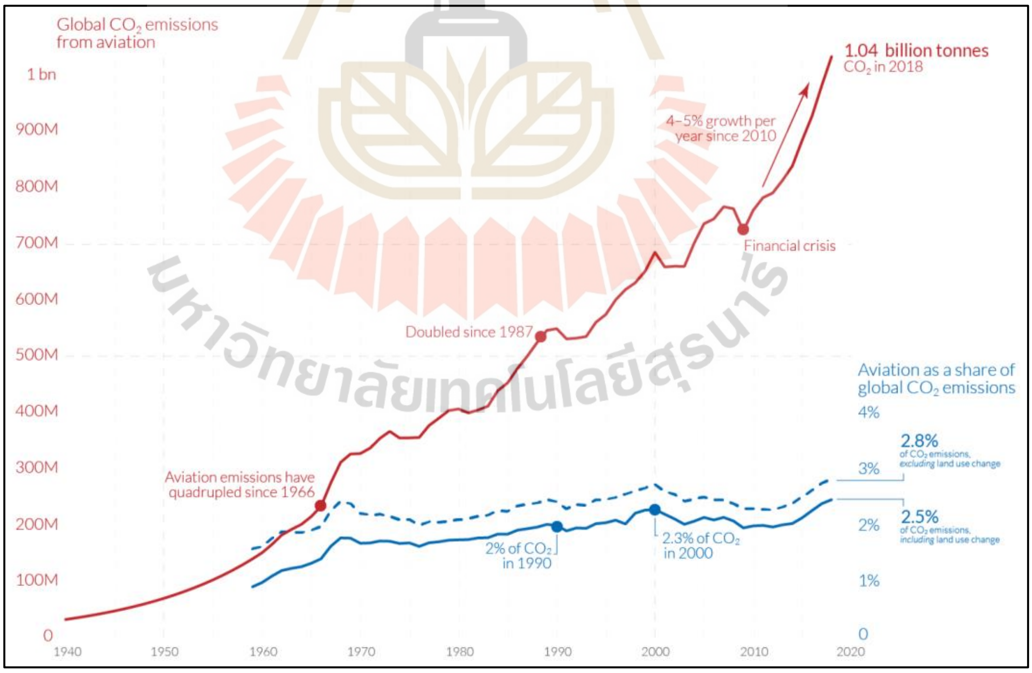

Figure 2.2 Global carbon dioxide emissions from aviation. *(Hannah Ritchie (2020))*

From Figure 2.2 depicts aviation emissions which includes passenger air travel, freight, and military operations. However, it does not account for non-CO_2 climate forcings or a multiplier to consider warming effects at altitude.

In accordance with ICAO guidelines, emissions originating from airport operations and domestic flights are administered by each individual Member States. However, emissions stemming from international flights are subject to the authority and responsibility of ICAO Itself. (ICAO. (2022))

2.3 SOLAR ENERGY

Solar energy is a sustainable and renewable energy source attained from the sun's radiation. There are multiple technologies used to harness and convert sunlight into either heat or electricity, given its extensive utilization across a multitude of applications, it distinguishes itself as the most prevalent choice. It stands out as one of the most environmentally friendly and rich in energy sources on planet Earth.

There are two primary methods to collect and take advantage of solar energy:

2.3.1 **Photovoltaic (PV) Solar Power**: Widely known as solar panels, are utilized to directly transform solar rays into electrical energy. These panels implemented usually consist of semiconductor materials like silicon, generating an electric current when exposed to the sun's radiation. The electric current produced is subsequently utilized to supply energy for residential, commercial, and electronic applications or can be stored in batteries for later utilization. *(ICAO. (2015)) (IRENA. (2023))*

Although an individual solar panel can produce electricity for specific applications, scaling up the energy production is achieved by increasing the surface area for light captured through the utilization of multiple solar panels. These individual solar modules are linked in a series (also commonly referred to as string), enabling the collective generation of electricity.

The electricity generated by each individual module accumulates at the termination point of the string. Multiple strings contribute their generated electricity to a combiner box until the accumulated electricity reaches the point of consumption or distribution. Notably, the solar facility generates electricity in the form of direct current (DC), while most electrical grids operate on alternating current (AC), facilitating shared access among numerous users from a single system. To bridge this setback, the solar facility incorporates an inverter responsible for the conversion of DC to AC electricity. Following this conversion, the electricity is either utilized on-site or fed into the electrical grid. Once integrated into the grid, solar-generated electricity becomes indistinguishable from electricity sourced through other conventional methods. *(ICAO. (2015))*

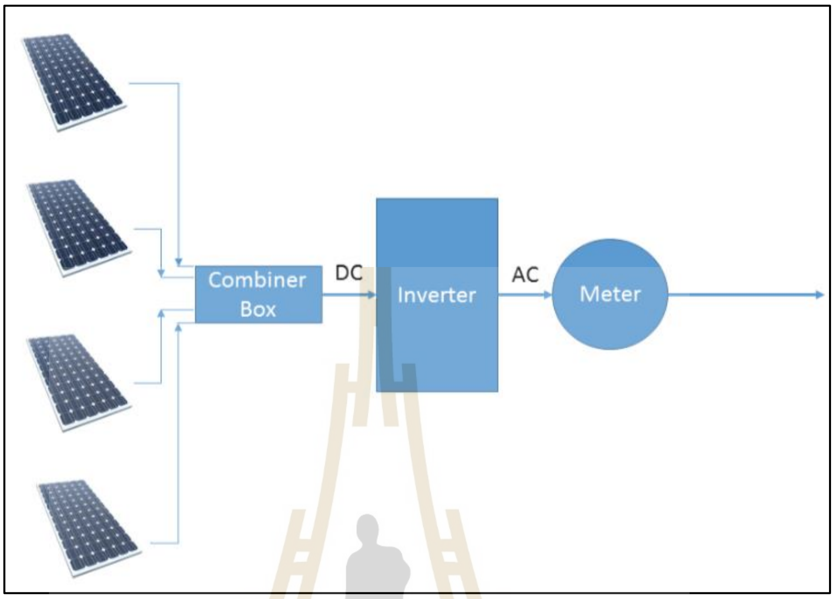

Figure 2.3 A string of solar PV modules. *(ICAO. (2015))*

The use of solar PV modules offers several distinct advantages, which can be summarized as follows:

1) Modular Scalability: Solar PV systems are inherently modular, allowing for easy adjustments in system size by simply increasing or decreasing the number of solar modules. This flexibility enables the customization of solar PV systems to match specific area requirements.

2) Versatile Placement: Solar PV systems boast remarkable flexibility in terms of their siting. This versatility arises from their modular construction and the flat design of the panels, which can be affixed to various locations. Panels can be mounted on poles in open, unused areas or attached to pre-existing manufactured structures properly oriented to receive ample natural light.

3) Universal Deployment: Solar PV technology can be effectively deployed on stable land anywhere in the world, harnessing sunlight that is available in varying degrees across all regions. While the efficiency and electricity output vary based on local sunlight levels, the optimization of power production primarily hinges on economic factors, encompassing considerations of the cost of replacing existing electricity sources and labour expenses for installation.

4) Predictable Electricity Generation: Solar facilities can reliably predict their electricity output for a given location based on an understanding of local climate conditions. This predictability is advantageous as it minimizes year-to-year variations in electricity production, subsequently reducing financial risk when aligning capital investments with anticipated revenue or savings from future electricity generation.

The main drawback of solar PV technology lies in its dependency on daylight, rendering it incapable of continuous electricity generation during night-time hours. To ensure a consistent and stable electricity supply for an electrical grid, alternative energy sources must be employed to compensate for the night-time deficit. While it is feasible to store solar electricity in batteries for nocturnal use, this approach can escalate the overall cost of an already potentially expensive electrical system. The more conventional alternative is to draw electricity from the grid after dark, and this has become the prevailing choice.

Furthermore, solar PV may not be an especially efficient method of electricity production when accounting for night-time periods, as well as factors such as inclement weather, overcast days, and fluctuations in daily output. In an ideal scenario where, solar panels operate at their rated capacity continuously, they would achieve 100 percent of their potential. However, real-world considerations such as night-time hours, weather disruptions, and geographical location typically result in solar panels achieving only an average of approximately 15 percent of their potential. This means that other renewable energy technologies, such as wind and hydro, may offer greater efficiency and reliability in electricity production.

2.3.2 **Solar Thermal Power**: Solar thermal systems utilize the solar rays to heat a fluid, such as water or other specialized heat-transfer fluid, to produce steam. Following this, the steam can eventually drive generators or provide direct heating. This can be attained by using two types of solar thermal systems.

The first system being, concentrated solar power (CSP), which makes use of mirrors or lenses to concentrate sunlight for high-temperature steam generation. And the second system is the solar water heating systems, designed to directly heat water, to serve residential or industrial needs such as space heating or hot water. *(IRENA. (2023)) (Solar energy - the official portal of the UAE Government (2022))*

Solar energy's eco-friendliness generates no greenhouse gas emission in operation, is vastly available (with the sun providing a limitless energy source), and potentially reduce the electricity expenses and fossil fuel dependency, boasts several advantages to using it as the main energy source. Nevertheless, it does have some caveat. Such as the availability of sunlight, the initial costs for setting up the solar panels, and the essential requirement for an effective storage solution.

2.4 WIND ENERGY

When it comes to energy production, wind energy is widely recognized that it is not linear but can achieve exponential growth in energy production in proportion to wind speed. This exponential relationship signifies that even a marginal increase in wind velocity results in a substantial cubed increase in energy output. Consequently, the wind energy industry places a significant emphasis on optimizing the electricity generation capacity of individual wind turbines, formerly known as 'windmills' but now referred to as 'wind turbine generators' (WTGs). To achieve economic viability in wind power generation, it requires consistently strong and reliable wind conditions. In the modern adaptation of wind power, an electrical generator is interposed between the wind source and the power output, facilitating the conversion of wind energy into electricity. Wind has a historical precedent spanning century, serving various purposes such as propelling boats, pumping water, and milling grains." *(ICAO. (2015))*

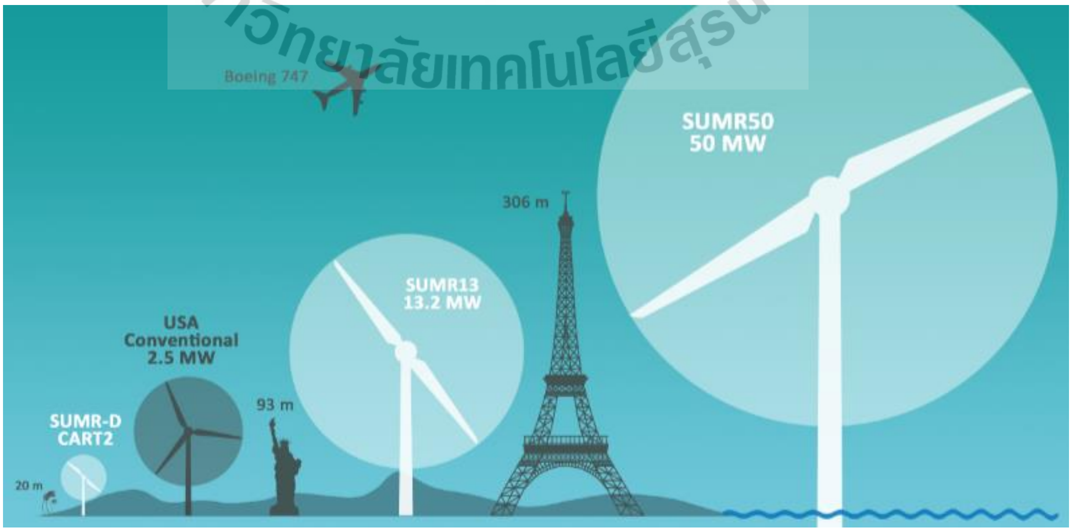

Figure 2.4 Typical size of a WTG compared to other structures. *(ICAO. (2015))*

Wind power projects are typically located in areas known for their substantial wind resources. These regions encompass flat plains, elevated ridges, and coastal zones. In more recent developments, large-scale wind farms have been established offshore near populated areas to take advantage of unobstructed wind flows. *(IRENA. (2023))*

In the pursuit of harnessing even greater wind energy, taller Wind Turbine Generators (WTGs) have been designed, featuring larger windswept areas akin to sails. Offshore WTGs, for instance, reach heights of up to 175 meters above sea level, with blade lengths extending to 75 meters. These taller turbines have significantly raised the capacity factor of individual generators, enabling them to achieve over 40 percent of their maximum rated output, often referred to as the Nameplate capacity. For instance, one Danish offshore wind farm has maintained an impressive capacity factor of 47 percent throughout its operational history. In contrast, solar PV systems typically operate at approximately 15 percent of their nameplate capacity. *(ICAO. (2015))*

Wind power has emerged as the second most prominent source of renewable energy globally since 2014, ranking just behind hydropower. It also stands as the second-fastest-growing technology worldwide, second only to solar energy. *(IRENA. (2023)) (ICAO. (2015))*

2.5 HYDROPOWER ENERGY

Hydropower, which harnesses the energy of flowing water to generate electricity, stands as the largest contributor to global renewable energy production. According to IRENA's 2016 statistics, hydropower accounted for 74 percent of the world's total renewable energy generation in 2014. *(IRENA. (2023))*

Throughout history, people have harnessed the power of rivers for various purposes, including transportation, water pumping, and grain milling. Waterpower played a crucial role in driving the Industrial Revolution, which commenced in Great Britain and later extended to Europe and North America during the late 18th and early 19th centuries. In the late 1870s, modern hydroelectric power was demonstrated, and within three decades, hydroelectric power stations began to emerge, from locations such as Niagara Falls to the Tanglangchuan River in China. Major hydroelectric power stations capable of supplying substantial regional power have continued to be constructed throughout the 20th century and into the present day. For example, Brazil has expanded its electricity production by 40 percent over the past decade, with four-fifths of this increase coming from hydroelectric stations. *(ICAO. (2015)) (IRENA. (2023))*

While hydropower remains a cost-effective method for providing stable, renewable electricity to regions lacking power infrastructure, it is important to note that damming rivers can result in ecological damage. To mitigate these impacts, a subset of hydropower technologies has been developed, aiming to generate electricity from flowing water without the need for dams. Turbine technologies placed in flowing rivers are referred to as run-of-the-river hydro, and other innovative methods are being explored to capture energy from waves, tides, and ocean currents. These technologies are still in their initial stages and are primarily undergoing testing.

Table 2.1 Countries generating all electricity from renewable sources in 2016 (GWh) (source: IRENA).

Country	Power	Hydropower	Other Renewable	% of Total
Albania	4,245	4,245	--	100
Bhutan	6,745	6,745	--	99.99
Burundi	200	200	--	99.99
Democratic Republic of Congo	7,852	7,852	--	99.98
Ethiopia	6,694	6,649	45	99.98
Iceland	17,423	12,214	5,209	99.87
Lesotho	486	486	--	99.71
Mozambique	14,994	14,994	--	99.58
Nepal	3,498	3,498	--	99.49
Paraguay	59,630	59,630	--	99.43
Zambia	11,696	11,696	--	99.01

Remark *Ethiopia = 29 GWh Wind, 16 GWh Geothermal; Iceland = 5,209 GWh Geothermal (ICAO. (2015))

Hydropower boasts a significant advantage over most other renewable energy sources, particularly solar and wind. The key benefit is the ability to store water behind a dam, which allows for the controlled management of water flow and, consequently, power output. This unique feature positions hydropower as the sole "base load" renewable energy source. However, it is worth noting that, once considered carbon-free, recent studies have revealed that reservoirs behind dam impoundments release methane, a greenhouse gas that carries carbon. Solar and wind electricity, on the other hand, are only available when the sun is shining or the wind is blowing, unless a costly battery storage system is integrated.

Furthermore, given that hydropower generates a substantial amount of electricity across extensive regions, the populations relying solely on hydropower are among the first in the world to access carbon-free electricity.

2.6 GEOTHERMAL ENERGY

Geothermal energy is a renewable power that utilizes the Earth's internal heat. These geothermal power plants work in a manner reminiscent of traditional fossil fuel stations, where the heat generated is utilized to create steam. This steam, in turn, powers a steam turbine connected to a generator, effectively generating electricity. However, it is important to note that geothermal power generation is location dependent. Not all areas have the geothermal resources required for this process. *(ICAO. (2015)) (U.S. Department of Energy. (n.d.))*

In the process of generating electricity using geothermal energy, a series of steps are involved. First, hot water is extracted from deep underground through a well, under high pressure. As this water rises to the surface, the pressure decreases, leading to a transformation from hot water into steam. The generated steam, a potent force, then drives a turbine, which is linked to a generator, the primary electricity producer in this system. After its job is done, the steam is cooled off in a cooling tower and condenses back into water. This cooled water is then pumped back into the Earth to initiate the cycle once more. *(IRENA. (2023)) (U.S. Department of Energy. (n.d.))*

This method offers a consistent and sustainable way to produce electricity in areas where geothermal resources are abundant. It is worth emphasizing that while geothermal power is a promising renewable energy source, its applicability is contingent on the specific geological conditions of the region.

2.7 TECHNICAL ASPECTS

2.7.1 Parabolic Trough

The parabolic trough operates according to the principles of a Concentrated Solar Power (CSP) system, wherein elongated curved concave mirrors are systematically aligned in a linear configuration to concentrate solar irradiance onto a conduit situated at the focal point of each mirror. This accumulated solar energy is subsequently converted into electrical energy.

The parabolic trough collectors are equipped with solar trackers that autonomously follow the sun's trajectory from east to west, optimizing the collection of solar radiation during the designated period. Within the focal point, a heat transfer fluid (HTF) circulates through the pipes. This HTF is a blend composed of diphenyl and biphenyl oxide, such as Therminol VP1, Downtherm A, or an equivalent, maintained at a temperature of 12 degrees Celsius. Throughout daylight hours, the parabolic trough captures solar radiation at the focal point, raising the HTF's temperature to 393 degrees Celsius. Depending on the situation, the HTF flow is directed either towards the steam generator or the thermal storage system. *(Noor Energy. (n.d.))*

The parabolic trough functions in various modes. In each operational mode, main steam is generated at 380 degrees Celsius and 100 bars of pressure. This steam passes through separate parallel sets of heat exchangers. Another parallel chain of heat exchangers is employed to reheat the steam. These heat exchangers cool the HTF, which is then directed back to the solar panels for reheating, and this cycle repeats. Any excess energy is directed to the Thermal Energy Storage (TES) system. *(Noor Energy. (n.d.)*)

The HTF serves as the conduit for transferring heat between the solar field and the water-steam cycle generation plant. The generated steam is sent to a steam turbine, which is connected to an electricity generator. The steam-water cycle adheres to the principles of the Rankine cycle.

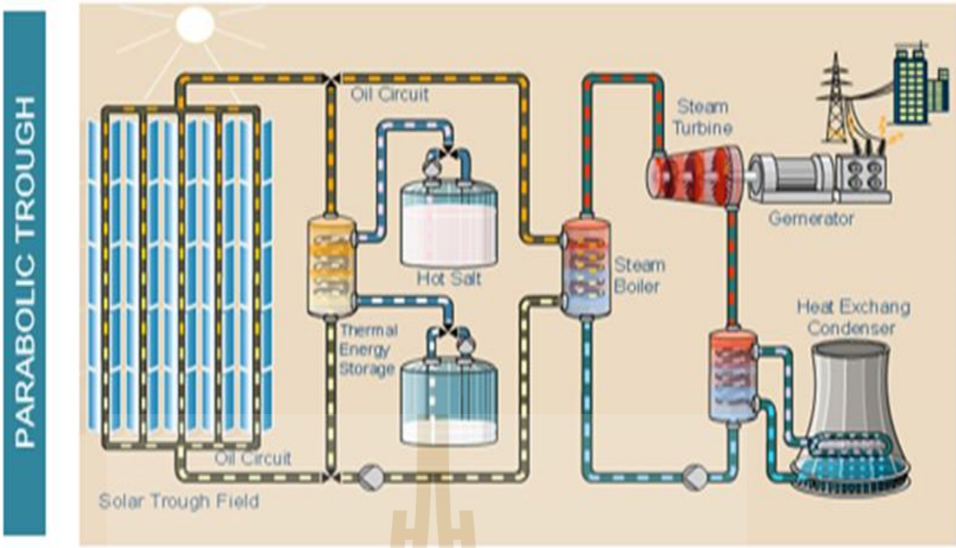

Figure 2.5 Parabolic Trough schematic diagram. *(Noor Energy. (n.d.))*

2.7.2 Central Tower

The primary role of the central tower is to transform the harvested solar energy, collected from an array of heliostats in the solar field, into electrical power. This conversion process occurs through a solar receiver situated at the pinnacle of the central tower, strategically positioned at the centre of the solar field. Additionally, the central tower serves as a thermal energy storage system, capable of retaining energy for up to 7 hours utilizing nitrate salt, and it facilitates a steam cycle in collaboration with a turbo generator, which is rated at 100 MW during standard operating conditions.

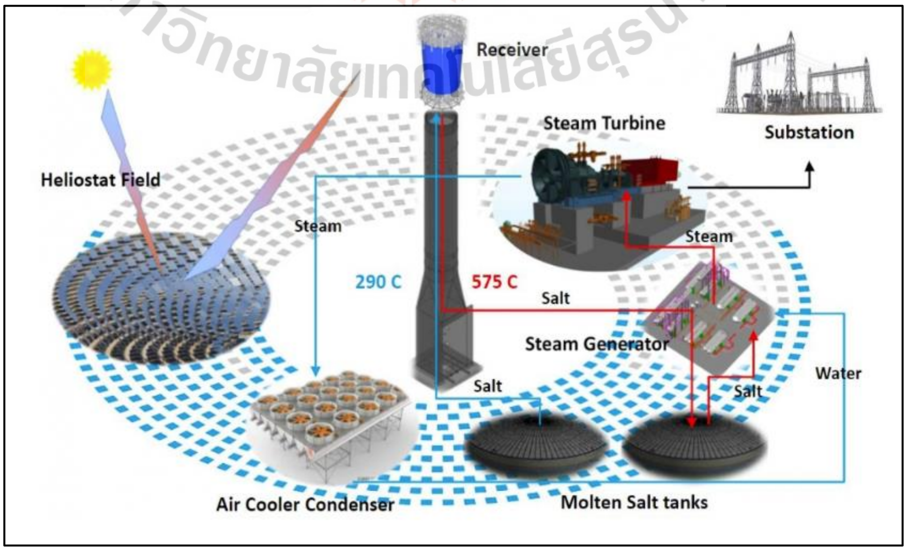

Figure 2.6 Central Tower diagram. *(Noor Energy. (n.d.))*

The collector system of the solar plant is composed of heliostats, specialized devices exclusively designed for redirecting sunlight towards the receiver. These heliostats are precisely positioned at an angle that optimizes sun exposure using mirrors and supporting structures. Once sunlight is effectively concentrated and directed onto the receiver, it undergoes a conversion process, transforming solar energy into thermal energy. This conversion is achieved through heat exchangers located within the pipes of the receiver. As a result of this energy conversion, nitrate salts are heated to temperatures ranging from 300 to 565 degrees Celsius. These nitrate salts, serving as heat exchangers, are initially stored in a cold salt storage tank at a temperature of 300 degrees Celsius. They are subsequently pumped to the receiver via an inlet vessel. *(Noor Energy. (n.d.))*

The heated salts are then conveyed to the outlet tank, where they maintain a temperature of 565 degrees Celsius as they exit the receiver. These hot salts play a crucial role as a buffer within the hot salt system.

These salts are stored within the hot salt tank and subsequently transported to facilitate the process of steam generation. The generation of steam is accomplished through the utilization of salt/water heat exchangers. The primary role of these salts within the solar plant is to serve as a heat exchanger during the phase involving the heliostats and receiver while also functioning as a coolant when superheated steam is produced. The steam generated is directed towards a turbine responsible for driving an electric generator, with the resulting electricity being later supplied to the grid.

The plant operates exclusively during daylight hours when sunlight is available. However, during periods when the plant is not operational, a discharge procedure is initiated. In this process, the salt circulation pumps are shut down, the pump contents are emptied, and the circulation of salt is carefully managed. This procedure is vital for ensuring a continuous supply of salt to the steam generator. It is imperative to maintain the salt in a liquid state at all times. To achieve this, electric resistance elements are submerged within the salt storage tanks, accompanied by a pipe tracing system and salt pipe accessories. *(Noor Energy. (n.d.))*

2.8 RENEWABLE ENERGY IN AIRPORTS

When it comes to energy usage in aviation sector, it is categorized as airport operations and aircraft. Energy in airport is essential to facilitate transportation efficiently for individuals and cargos. An airport of large-scale functions as a self-contained urban area, demanding substantial public infrastructure, including water supply network, roads, and electrical grids, to accommodate the influx of travellers. Conversely, airports of smaller scale may serve as a central hub in certain areas with minimal or underdeveloped infrastructure, relying on localized resources like water and power.

Airport energy expenses are substantial. In the United States, energy expenses typically account for 10% to 15% of airports' operational budget. Remarkably, aside from personnel costs, it stands out as the most considerable single expense incurred in airport operations. Despite largest airports being the most significant consumers of energy, interestingly, they also exhibit a high degree of efficiency when evaluated on a per-passenger basis.

Through external providers, heating fuel and electricity are sourced with heating typically relying on oil or gas delivered via pipelines or trucks. Whereas electricity obtained from the national grid, are powered by a central plant utilizing diverse sources of energy such as gas, oil, coal, and nuclear, or renewable energies like solar, wind, or hydroelectric power. Through this, it can serve a wide range of purposes, including powering computer systems, radar equipment, and terminal lighting. When an aircraft is parked at the gate, they are energised either by the jet fuel in their auxiliary power unit (APU), group support equipment (GSE) operating on the apron using diesel or gas, or electricity from the terminal.

There are four renewable energy resources that provide the most proficient electricity generation to meet the airport's electrical requirements, thanks to technological advancements. These include, solar PV, wind power, hydroelectricity, and geothermal energy. (See in Figure 2.7)

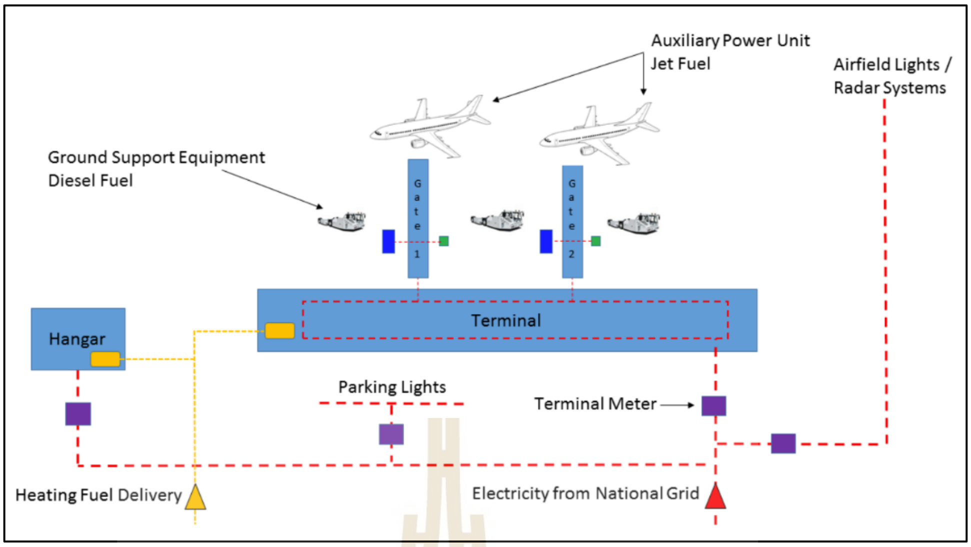

Figure 2.7 Various energy consumption activities within an airport setting. *(ICAO. (2015))*

2.8.1 SOLAR PV TECHNOLOGY

Due to its ability to integrate with existing development and low profile, solar PV is remarkably compatible with airports as it can be attached to existing or future building's structure. Its design also mitigates the risks associated with physical obstructions and safety concerns, other challenges that can arise when attempting to place other renewable technologies, such as wind power, near airports.

Solar PV can also be situated in various locations on the airfield, near runways, without causing any physical congestion on airspace. However, one potential concern related to solar PV pertains to glare, which can potentially affect incoming aircraft and the air traffic control tower. This is due to the solar panel's smooth and reflective surfaces, resulting in glares especially when the sun is at a low angle and produce a glancing reflection. In these cases, project developers must assess the potential for visual impairment to air traffic controllers, pilots, and any other sensitive receptors located on or near airport premises during the project's placement phase to ensure the solar project do not cause any glare-related issues. *(ICAO. (2015))*

2.8.2 WIND TECHNOLOGY

Due to the requirement for constructing elevated structures to harness sufficient wind, wind turbine generators (WTGs) are not a practical choice for airport installations, as they are likely to impinge upon the airport's airspace. Despite that, tall wind turbines reaching heights of 35 to 50 meters above ground, in limited number, have been situated on airport grounds while adhering to airspace protection regulations. Even though, there may be some potential to place taller WTGs at airports with considerable separation between a WTG and airport runways, the likelihood of risks to aircraft safety tend to outweigh the benefits of implementing such projects.

As an alternative approach, various airports have undertaken the construction of building-integrated wind turbines. These designs involve installing 10 – 20 small-scale wind turbines on the rooftops of airport structures. Typically, for large-scale WTGs, each wind turbine generates electricity at a peak output capacity, equivalent to that of four solar modules operating at their maximum potential. Nonetheless, the building-integrated turbines lacks the efficiency components found in larger WTGs, such as the substantial blade area and an elevated position of 150 meters above ground level, leading to turbines not rotating as frequently as needed, resulting in a significant reduction in efficiency. While these projects, often visible, can serve as a symbolic gesture of an airport's interest and dedication to renewable energy, it is crucial to recognize that they are unlikely to generate a substantial quantity of renewable energy capable of accomplishing significant reductions in emissions. *(ICAO. (2015))*

2.8.3 HYDRO TECHNOLOGY

Hydropower has a well-established record of accomplishment for producing substantial quantities of renewable energy, however, it requires a considerable upfront investment for project development. The costs cover not only capital expenditures for land, concrete, electric turbines, and sophisticated control systems but also includes development expenses related to permitting and research, which introduces significant financial risks. This is partly attributed to concerns regarding the environmental repercussions of hydroelectric ventures. Hydropower is a technology that, for most part, makes sense when implemented on a large scale to cater to grid-based applications rather than on-site utilization, with exceptions being contingent on the specific site location and resource availability. *(ICAO. (2015)) (U.S. Department of Energy. (n.d.)) (IRENA. (2023))*

2.8.4 GEOTHERMAL TECHNOLOGY

Like hydropower, geothermal power stations must be built on a substantial scale to achieve economic viability in supplying electricity to national grid. Geothermal energy is highly site-dependent, with economically feasible development opportunities primarily concentrated in regions where the Earth's core heat is accessible near the surface.

Consequently, geothermal electricity does not offer a practical option for on-airport implementation. However, a specific variant of geothermal energy known as "ground source heat pump" has been employed at airports, utilizing renewable thermal energy.

Ground source heat pump also known as Geothermal heat pump systems have been integrated into new construction and renovation projects for terminal buildings in North America and Europe. These projects have displayed their effectiveness in providing renewable thermal energy for extensive heating and cooling demands. Given that these systems' efficiency is contingent on ambient temperatures, which can exhibit substantial fluctuations, it is not unusual for projects to undergo an extended commissioning phase to fine-tune the systems to suit the facility's needs and enhance their operational performance. Geothermal heat pump systems prove most economically viable when integrated into new construction or extensive renovation efforts since they may require the installation of new heating and cooling distribution networks within the building. *(ICAO. (2015)) (U.S. Department of Energy. (n.d.)) (IRENA. (2023))*

2.8.5 SOLAR THERMAL TECHNOLOGY

Solar thermal panels have been implemented at numerous airports. Much like solar PV, solar thermal panels can be affixed to airport building rooftops to provide thermal energy for those structures. This design concept exemplifies the technical viability of implementing such systems. Solar thermal technology, particularly proficient at providing hot water of domestic and commercial purposes, has seen more successful adoption in residential and commercial contexts where hot water demands are substantial. Since airports typically have lower hot water requirements, the practicality of employing solar thermal systems in these settings has not been extensively documented. Furthermore, the cost of solar thermal installations exceeds that of solar PV, leading airports to prefer solar PV solutions. It is important to evaluate solar thermal facilities at airports for potential issues related to glare. *(ICAO. (2015))*

2.8.6 BIOMASS TECHNOLOGY

Airports have, in limited instances, turned to biomass as a heat source for their building requirements. Typically, these initiatives have involved the substitution of conventional fossil fuel boilers with biomass-fuelled counterparts. Such projects have frequently been sighted in regions with existing forest resources and a ready supply of processed biomass-related wood fuel. In certain cases, securing storage space for biofuel and coordinating the timing of biofuel deliveries have emerged as pivotal considerations for larger airport projects. The cost-effectiveness of these initiatives depends on the relative cost of biomass fuel in comparison to other available sources. *(ICAO. (2015)) (IRENA. (2023))*

2.9 BIOFUEL

Biofuel or sustainable aviation fuel (SAF) in the context for aviation, refers to a type of renewable fuel derived from biological sources, such as plants, algae, or animal fats. It is considered an alternative to traditional fossil fuels and is produced through processes like biomass conversion, pyrolysis, or transesterification. The primary objective of using biofuels in aviation is to reduce the environmental impact of air travel by lowering greenhouse gas emissions.

Aviation biofuels are typically categorized into two main types: bio-jet fuels and aviation biodiesel. Bio-jet fuels are designed to be used in aircraft engines, specifically in jet turbines. These fuels are formulated to meet the rigorous safety and performance standards required for aviation. They can be produced from various feedstocks, including feed crops, agricultural residues, or waste oils.

One notable advantage of biofuels in aviation is their potential to mitigate carbon emissions. When produced from sustainable sources, biofuels have the advantage of being carbon-neutral over their lifecycle. The carbon dioxide released during combustion is equal to the amount absorbed by the plants during their growth, creating a closed carbon cycle.

The aviation industry is actively exploring and adopting biofuels as part of its commitment to environmental sustainability. Airlines and aircraft manufacturers are conducting research and development to integrate biofuels into their fleets. Additionally, there is a growing emphasis on developing advanced biofuels with improved efficiency and reduced competition with food crops.

While biofuels offer a promising avenue for reducing the carbon footprint of aviation, challenges remain. These challenges include the scalability of production, competition with food production, and the need for continued technological advancements to make biofuels more economically viable and readily available for the aviation sector. (*U.S. Department of Commerce. (n.d.)) (IATA. (2023))*

2.10 EXISTING RENEWABLE ENERGY IN UAE

The prevalent solar Direct Normal Irradiance (DNI) intensity ranges from 5.5 to 5.7 kWh/m^2 per day and is found in the southern region of the country. Meanwhile, the prevailing wind speeds, exceeding 5.5 m/s annually at a height of 50 meters, are distributed in the north-eastern part of the country, along the Gulf of Oman coastline, and in the north-western part of the country, along the Persian Gulf coastline. In 2019, the installed generating capacity for electricity in the United Arab Emirates amounted to 32.3 gigawatts (GW). *(AENERT. (2023))*

Table 2.2 List of energy infrastructure in the UAE

Solar PV Power Plants	1. Al Dhafra Solar PV 2. The Noor Abu Dhabi Solar Power Plant 3. Mohammed bin Rashid Al Maktoum Solar Park 4. Masdar City 5. Jebel Ali
CSP Power Plants	1. Shams 2. Noor Energy DEWA IV (Parabolic Trough) 3. Noor Energy DEWA IV (Tower)
Wind Power Plants	1. Sir Bani Yas
Nuclear Power Plants	1. Barakah
Gas Power Plants	1. Jebel Ali Complex 2. Al Taweelah A1-A2 & B 3. Shuweihat S1-S2-S3 4. Qidfa 1-2 5. Umm Al Nar 6. Al Aweer 7. Wasit 8. Al Taweelah, EMAL 9. Dubai Aluminium, DUBAL 10. Ruwais
Oil Power Plants	1. Madinat Zayed

Table 2.2 List of energy infrastructure in the UAE (Con't)

Pumped-storage Plants	1. Hatta Hydroelectric Power Plant
	400 kV operational power line
	A 400 kV connection points in the national grid linking various power plants and substations
	Border crossing

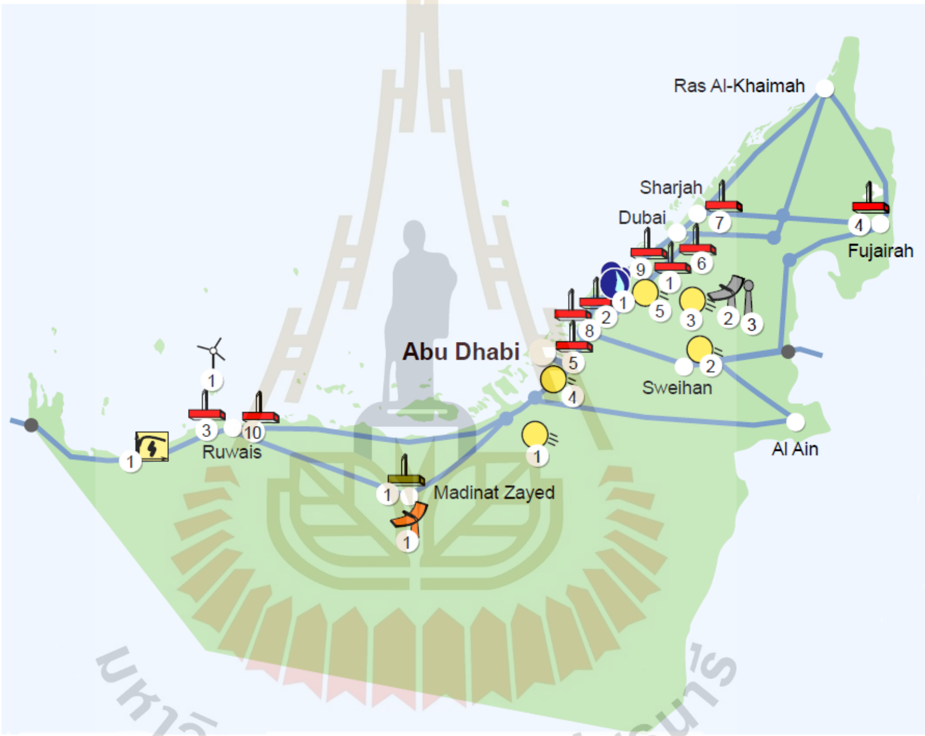

Figure 2.8 Electricity and Renewable Energy Sources in the UAE *(AENERT. (2023))*

2.11 RENEWABLES INITIATIVES OF UAE FOR AVIATION

2.11.1 Emirates pledges to commit $200 million over three years to funding sustainable aviation R&D

In May 2023, Emirates, the world's largest international airline based in Dubai, has committed to invest $200 million over the next three years to support research and development in advanced fuel and energy technologies for commercial aviation. The airline argues that existing efforts to decarbonize air transport are insufficient and aims to accelerate the development of innovative solutions. This initiative, declared during the United Arab Emirates' 'Year of

Sustainability,' marks the largest single commitment by any airline toward sustainability. Tim Clark, Emirates Airline President, emphasized the need for better solutions and expressed the airline's intention to collaborate on R&D with leading organisations. He stated that their goal is make a meaningful contribution to practical solutions for the long-term sustainability of commercial aviation. *(Emirates. (2023))*

The commitment follows a proof-of-concept test flight earlier this year, where an Emirates Boeing 777-300ER operated with one engine powered by 100% sustainable aviation fuel (SAF). Emirates seeks regulatory approval to operate commercial flights with 100% SAF, double the current limit of 50%. The airline, a partner in various working groups and stakeholder engagements, acknowledges the global scarcity of SAF and aims to explore alternative paths for decarbonization.

The $200 million R&D fund will focus on advancing new fuel and energy technologies, addressing the significant challenges faced by airlines in reducing environmental impact. The Emirates Environmental Sustainability Executive Steering Group, with the assistance of external technical experts, will oversee the distribution of research funds. The airline, operating a fleet of 260 Airbus A380 and Boeing 777 aircraft, with additional orders for 200 new, more fuel-efficient jets, practices environmentally responsible measures in fleet operations, including the use of SAF where feasible. *(Emirates. (2023))*

Emirates' initiative aligns with sustainability partnerships by major carriers like United Airlines, emphasizing the industry's collective commitment to advancing sustainable aviation technologies.

2.11.2 Masdar and Boeing Join Forces to Accelerate the Sustainable Aviation Fuel Industry in the UAE and globally

In October 2023, Abu Dhabi Future Energy Company PJSC (Masdar), a leading global renewable energy firm with expertise in green hydrogen, has joined forces with aerospace giant Boeing in a strategic collaboration to drive advancements in the sustainable aviation fuel (SAF) sector, both within the UAE and on a global scale. This partnership is aligned with the shared objective of the commercial aviation industry to achieve net-zero emissions by 2050. The Memorandum of Understanding was formally executed by Mohammad Abdelqader El Ramahi, Chief Green Hydrogen Officer at Masdar, and Kuljit Ghata-Aura, President for the Middle East, Türkiye & Africa at Boeing, during the Abu Dhabi International Petroleum Exhibition and Conference (ADIPEC) 2023. Together, Masdar and Boeing are committed to promoting the formulation and adoption of SAF policies, with an emphasis on exploring innovative SAF accounting principles to surmount geographical challenges as the industry expands. SAF, derived from sustainable sources such as green hydrogen, has the potential to slash carbon emissions by up to 85% throughout its lifecycle when compared to traditional petroleum jet fuel. Acknowledged as a viable drop-in replacement for up to 50% of standard jet fuel, SAF presents the most substantial opportunity to curtail carbon emissions across various aviation segments over the next three decades. Additionally, Masdar has announced its active involvement in a green hydrogen-focused initiative, collaborating with licensors to certify a new SAF production pathway from methanol, as revealed during Abu Dhabi Sustainability Week earlier this year. *(Masdar. (2023))*

Mohammad Abdelqader El Ramahi, Chief Green Hydrogen Officer at Masdar, emphasized the importance of international collaboration and innovation in achieving global net-zero goals. Proudly representing the UAE's clean energy prowess, Masdar is partnering with Boeing, a global leader in aerospace, to drive the development of sustainable aviation fuel projects. Their collaborative efforts extend to advocating for enabling policies crucial for fostering this key market. In preparation for the UAE's hosting of COP28, they aim to leverage their combined knowledge, expertise, and passion to support the industry and contribute to a more sustainable future. *(Masdar. (2023))*

Kuljit Ghata-Aura, President of Boeing Middle East, Türkiye, and Africa expressed excitement about the collaboration with Masdar to lead the growth of the sustainable aviation fuel industry on both local and global scales. Recognizing the potential for job creation, economic growth, and significant business opportunities, he highlighted the pivotal role of SAF in aviation's decarbonization efforts. The partnership reflects over a decade of collaboration between Boeing and the UAE in sustainable aviation, underscoring their shared commitment to achieving net-zero emissions by 2050. *(Masdar. (2023))*

CHAPTER 3

RESEARCH PROCEDURE

3.1 INTRODUCTION

This chapter presents the research methodology of the study. The chapter covers research design for each phase, as well as methods of data collection and data analysis.

The methodology employed in this thesis adopts a qualitative methods to comprehensively analyse alternative renewable energy resources in the UAE's airports. This approach is essential for obtaining insights, results, and a comprehensive understanding of the intricate relationships and dynamics surrounding renewable energy adoption in airports. The information in this chapter is as follow:

1) Research Procedures
2) Instrument of data collection
3) Data collection
4) Data analysis

3.2 RESEARCH PROCEDURE

The methodology for the thesis will consist of the following approaches:

3.2.1 Conduct an extensive literature review to gather information on the current state of airports in the UAE, including energy consumption, greenhouse gas emissions, and sustainable practices. Review existing studies, research papers, industry reports, and government policies related to airport sustainability and renewable energy integration.

3.2.2 Collect data on energy consumption, emissions, and operational practices from relevant aviation authorities and airport operators in the UAE. Gather past and current data on energy usage, emissions, and other relevant parameters.

3.2.3 Evaluate the feasibility of renewable energy sources, such as solar, wind, and piezoelectric technology, for integration into airport operations. Consider technical and economic aspects, including potential energy generation and cost-effectiveness.

3.2.4 Examine specific case studies of renewable energy projects and sustainability initiatives within airports in the UAE. Analyse the outcomes, challenges, and best practices of these projects.

3.2.5 Assess energy efficiency initiatives, technologies, and best practices employed in airport operations to reduce energy consumption and emissions. Identify opportunities for energy optimization and sustainability.

3.2.6 Apply SWOT analysis to assess internal and external factors influencing the adoption of alternative renewable energy in airports. This will help guide the research toward practical insights and recommendations.

3.2.7 Using a circuit simulation will serve as a fundamental tool in the analysis and evaluation of proposed electrical systems. Utilizing simulation software allows for a virtual representation of the circuitry, enabling a detailed examination of its behaviour under various conditions.

3.2.8 Develop theoretical recommendations and solutions based on the findings from the analysis, with a focus on enhancing energy efficiency, reducing emissions, and promoting sustainability in airport operations. In addition, explore potential challenges for sustainable airports in the UAE, considering emerging technologies, global trends, and long-term sustainability goals.

3.3 INSTRUMENT OF DATA COLLECTION

This research concentrated on analysing and evaluating the factors influencing the internal and external environment as well as the competitiveness of alternative renewable resources. The noteworthy insights derived were then implemented into the strategic plan of the entity to enhance its capacity to adapt to the environmental dynamics and compete effectively within the region. The primary instruments employed in this study were the SWOT Analysis and circuit simulation.

3.4 DATA COLLECTION

This thesis relies on a secondary research approach, drawing information from diverse sources to ensure a comprehensive examination. The internet serves as a primary source, leveraging its accessibility and wealth of information. Using this approach, government websites can be explored for trustworthy and authentic data relevant to the research, as well as educational institutions, particularly colleges and universities, would contribute significantly due to the extensive research conducted in academic settings. Commercial information sources, such as local newspapers and journals, provide varied viewpoints, and industry reports offer specialized and current insights. Additionally, a thorough review of existing academic literature and scholarly articles establishes a robust theoretical foundation, enriching the context of the research.

3.5 DATA ANALYSIS

The process of data analysis, involving verification and evaluation of data to uncover valuable information, draw conclusions, and aid decision-making, is implemented to establish the necessary framework through the following steps.

3.5.1 Verification of the relevance and adequacy of the contents in alignment with the study's objectives.

3.5.2 Analysis and organization of key content extracted from the literature review into relevant aspects.

3.5.3 Application of the SWOT Analysis to compare each alternative renewable energy source against one another.

3.5.4 Integration of circuit simulation to assess and model proposed electrical systems, providing a virtual representation for detailed examination.

CHAPTER 4

RESULT OF DATA ANALYSIS

The purpose of this chapter is to present the result of information analysis. The problem was intend to solve were to find alternative renewable energy for airport in UAE. From this it was necessary to examine first the Strengths, Weaknesses, Opportunity and Threats.

4.1 TO COLLECTION DATA THE ALTERNATIVE ENERGY SOLUTIONS WITHIN THE AIRPORT SECTOR IN THE UAE FROM THE DOCUMENT

4.1.1 Piezoelectricity

In the quest to achieve sustainable energy to be implemented into aviation practices and reduce the industry's environmental footprint, the pursuit of alternative renewable energy has gained significant momentum. Among these alternatives, piezoelectric technology can be viable as a promising alternative renewable energy within the aviation sector. This section presents the results of the investigation into the viability and effectiveness of piezoelectric systems as a source of renewable energy. Additionally, it will also include a unique approach on how to harness this energy to the aviation sector.

1) Piezoelectric Principles and Applications

Piezoelectric effect, or often referred to as piezoelectricity, is a phenomenon in which specific materials can produce an alternating current (AC) voltage when under mechanical stress or vibration. Additionally, these materials can also vibrate when subjected to an AC voltage or exhibit both behaviours simultaneously. Quartz is the most widely recognized example of a piezoelectric material, but effect is also observed in several ceramics such as Rochelle salts, and various other solid substances. *(TechTarget. (2016)) (Nano Motion. (n.d.)) (ScienceDirect. (n.d.))*

In practical terms, piezoelectric materials are effectively applied to develop devices and systems that can harness and convert mechanical forces, including vibrations and variations in pressure, into electrical energy. This energy can subsequently be captured and utilized for various applications or stored for future use. Moreover, these materials have the capability to transform electrical energy into mechanical energy, facilitating applications such as actuators in speakers and precise positioning mechanisms.

4.1.2 Piezoelectric Energy Harvesting at the Runway

Integrating the piezoelectric technology into the runway infrastructure opens new possibilities for energy generation. Due to its ability to convert mechanical energy into electrical power, it can play a pivotal role in making airport runways more than just surfaces for aircraft landings and take-offs.

1) Runway-Integrated Piezoelectric Systems

1.1) Energy Harvesting during Aircraft Landings: The force exerted by aircraft during landings and take-offs results in mechanical stress on runway surfaces. By integrating piezoelectric materials into the runway structure, this mechanical stress can be harnessed and converted into electrical energy. This harvested energy source can significantly contribute to powering runway lighting, navigational aids, and other essential airport systems.

1.2) Taxiway Energy Generation: In addition to runway landings, taxiways and other paved areas within the airport can also be equipped with piezoelectric systems. The back-and-forth movement of aircraft while taxiing generates kinetic energy that can be efficiently converted into electricity. This energy source can serve as an alternative or supplementary power supply for ground operations and services.

1.3) Sustainability and Environmental Impact: The implementation of piezoelectric systems in runway infrastructure aligns with the aviation industry's commitment to sustainability. It not only reduces the reliance on traditional energy sources but also mitigates the carbon footprint of airport operations. In theory, it could proof beneficial for the environment with this approach, particularly in terms of reduced greenhouse gas emissions.

4.1.3 Piezoelectric Circuit Design

The electronic circuit was designed using the online electronic simulator found at www.falstad.com/circuit/. In Figure 4.1, the piezoelectric circuit design is illustrated, with positive voltage represented by the green colour, negative voltage by the red colour, and ground indicated by the grey colour.

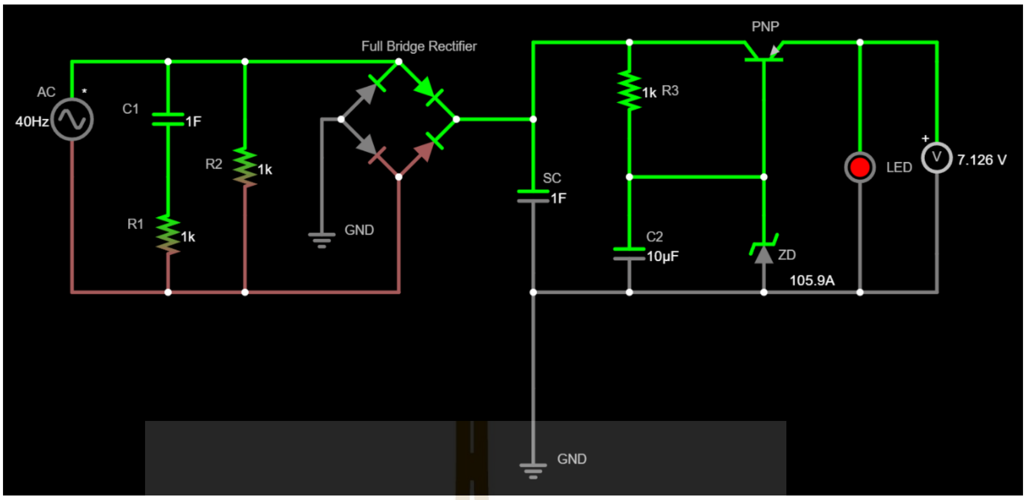

Figure 4.1 The main piezoelectric energy harvester design.

The circuit components include:

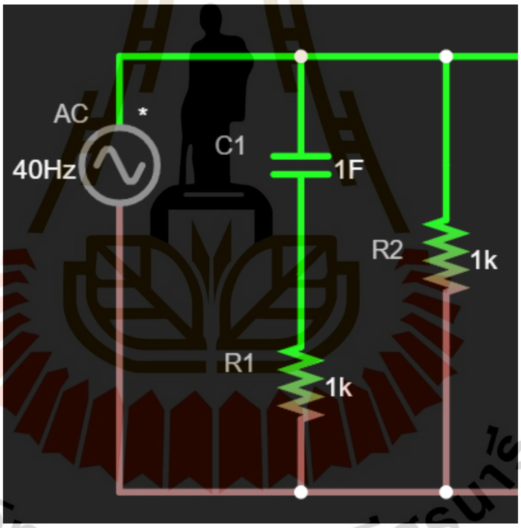

Figure 4.2 Piezoelectric generator.

1) AC voltage (AC) – Also known as Alternating Current voltage is the type of electrical voltage that periodically reverses direction. In an AC circuit, the electric charge changes direction, usually in a sinusoidal waveform. The input voltage in the circuit 10V with a frequency of 40 Hz.

2) Capacitor (C1, C2) – A capacitor is an electronic component that stores electrical energy in an electric field. It consists of two conductive plates separated by an insulating material (dielectric). Capacitors are used to store and release electrical energy in a circuit.

3) Resistor (R1, R2, R3) – A resistor is a passive electronic component that limits the flow of electric current. It is designed to introduce a specific amount of resistance into an electrical circuit, controlling the amount of current that can pass through.

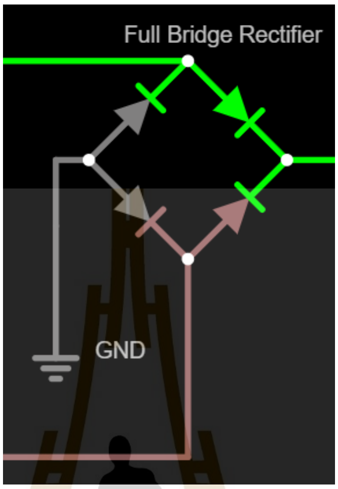

Figure 4.3 Full bridge rectifier.

4) Full bridge rectifier – A full bridge rectifier is an arrangement of diodes used to convert alternating current (AC) to direct current (DC). It utilizes four diodes configured in a bridge circuit to rectify the entire cycle of the AC waveform.

5) Ground (GND) – A node used as a voltage reference, usually chosen as a point of zero voltage potential. The ground in a circuit provides a stable reference point for voltage measurements and serves as a return path for electric current.

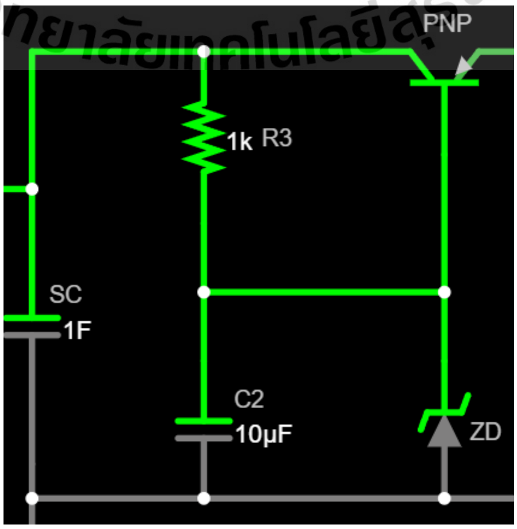

Figure 4.4 Regulator.

6) Supercapacitor (SC) – Also known as an ultracapacitor, is an energy storage device that stores electrical energy via an electrostatic mechanism. It has a higher energy density than traditional capacitors and can store and release energy rapidly.

7) Zener Diode (ZD) – A Zener diode is a type of diode that allows current to flow in the reverse direction when a certain voltage (the Zener voltage) is reached. It is often used in voltage regulation circuits to maintain a constant output voltage.

8) PNP transistor (PNP) – A PNP transistor is a type of bipolar junction transistor (BJT) that consists of three layers of semiconductor material. It allows current to flow from the collector to the emitter when a small current is applied to the base.

9) LED – Also known as light-emitting diode, is a semiconductor device that emits light when current flows through it. LEDs are commonly used as indicators, displays, and in lighting applications.

10) Voltmeter (V) – An electrical instrument used to measure the voltage, potential difference, or electric potential across two points in an electrical circuit.

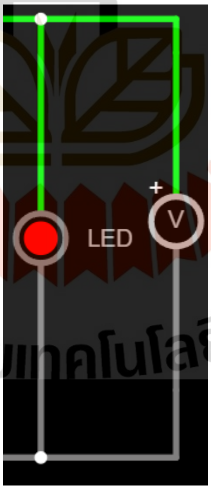

Figure 4.5 LED as the load and voltmeter to measure the voltage.

1) Circuit Operation

The system configuration involved capturing energy from the runway pavement using an energy harvester. The structure comprises a receiving circuit, a rectifier module, and a regulator module. In the receiving circuit, piezoelectric generators convert mechanical energy into AC voltage (this AC voltage is generated because of the piezoelectric effect in material like quartz or ceramics), which is transmitted through a full-bridge rectifier. Subsequently, the rectifier module rectifies (converts) the AC voltage into DC voltage, allowing the current to flow in one direction, and the resulting energy is stored in a 1F supercapacitor, functioning as an energy storage unit. The regulator module is then controlled by a linear regulator to supply a consistent DC voltage as the rectified DC voltage may have fluctuations. This stored energy is further regulated by the linear regulator to deliver a stable DC voltage. The LED represents as the load in this circuit, when the DC voltage reaches a sufficient level, it powers the LED, causing it to emit light.

The output energy from the circuit can power various aviation-related systems, such as:

- Aircraft ground systems, including Ground Power Units (GPU), air conditioning units, passenger boarding bridges.
- Maintenance equipment for routine maintenance repairs, and inspections of the aircraft which includes tools and machinery (Integrating the energy harvester with existing sustainable power solutions for maintenance equipment at airports).
- Ground control systems which include software and communication systems used by ground control personnel to manage and coordinate aircraft movements on the ground
- Airfield lighting systems, including runway lights and emergency lighting.

2) Basic Energy Calculations

The energy stored is directly proportional to the capacitance and the open circuit voltage. This means that the energy stored can be changed accordingly by calibrating the capacitance of the circuit and the input voltage. Mathematically, the energy stored is:

$$E_e = \frac{1}{2} C V_o^2$$ *(Piezo.com. (n.d.)) (All About Circuits. (2018))*

Where E_e is the stored electrical energy in joules, C is the capacitance in Farads, and V_o is the open circuit voltage in volts.

Using the stored electrical energy equation, we can input circuit values into the formula:

Where C is the Supercapacitance = 1 F

V_o is the output voltage as shown in figure = 7 V (approx.)

Inputting these values into the equation = 24.5 J

4.2 SWOT ANALYSIS

From the secondary data in 4.1 it can be apply SWOT analysis to assess internal and external factors influencing the adoption of alternative renewable energy in aviation as the following;

4.2.1 Piezoelectric (see in table 4.1)

Table 4.1 SWOT Matrix of Data Analysis for Piezoelectric

STRENGTHS	WEAKNESSES
S1 Renewable Energy Source	W1 Limited Power Output
S2 Low Environmental Impact	W2 Dependence on Mechanical Vibrations
S3 Versatility	W3 Difficulty in Sourcing Suppliers
S4 Long Lifespan	W4 Lack of Knowledge/Experience in Handling New Technology
S5 Low Maintenance Cost	W5 Lack of Skilled Manpower
S6 Government Support	
OPPORTUNITIES	**THREATS**
O1 Integration into Wearable Technology	T1 Competition from Other Renewable Sources
O2 Advancements in Material Science	T2 Cost and Scalability Challenges
O3 Low Investment Cost	T3 Limited Public Awareness
	T4 Bureaucracy

1) Strengths of Piezoelectric

As a renewable energy source, piezoelectricity can be harnessed from mechanical vibrations, such as footsteps, vibrations in machinery, or even natural movements like wind and waves. Its materials are known for their durability and long lifespan, making them a reliable source of energy over time. Also, the materials are often non-toxic and have a minimal impact on the environment. The process of generating electricity from these materials does not produce greenhouse gases or other pollutants. This inherent eco-friendliness contributes to the broader goal of adopting cleaner energy sources in the face of global environmental challenges. The versatility of piezoelectric devices is a key strength that can be used in various applications, including energy harvesting, sensors, actuators, and even in medical devices. This versatility makes piezoelectricity suitable for a wide range of industries. Piezoelectric devices have minimal maintenance costs, making them economically attractive for long-term use. This technology benefits from strong governmental support, fostering its growth and development in various industries. The combined strengths of piezoelectricity in environmental impact, versatility, durability, cost-effectiveness, and government endorsement position it as a promising alternative in the renewable energy landscape.

2) Weaknesses of Piezoelectric

When it comes to weaknesses, the amount of power that can be generated from piezoelectric materials is often limited compared to other forms of renewable energy like solar or wind power. This limitation may restrict its use in certain applications. Piezoelectricity relies on mechanical vibrations to generate electricity. In situations where these vibrations are scarce or insufficient, the efficiency of piezoelectric devices may be compromised. The piezoelectric industry may face challenges in finding reliable suppliers, impacting the consistent and timely availability of necessary components. Furthermore, the industry may face a shortage of skilled professionals proficient in working with piezoelectric devices, hindering their effective utilization. The relative novelty of piezoelectric technology may result in a lack of expertise or experience among users, affecting its widespread adoption.

3) Opportunities for Piezoelectric

Piezoelectric technology presents an opportunity for industries to benefit from low initial investment costs, potentially encouraging wider adoption and application in diverse fields. The small size and flexibility of piezoelectric materials make them suitable for integration into wearable devices which could lead to self-powered wearable technology, reducing the reliance on batteries. Additionally, ongoing advancements in material science may lead to the development of more efficient and cost-effective piezoelectric materials, expanding the range of applications and improving overall performance.

4) Threats for Piezoelectric

Piezoelectricity faces competition from other established and emerging renewable energy sources, such as solar and wind power. The level of competition could impact the adoption and investment in piezoelectric technology. The cost of manufacturing and implementing piezoelectric devices, as well as challenges related to scalability, could hinder widespread adoption. If cost-effective solutions and scalable manufacturing processes are not developed, piezoelectricity may struggle to compete with other energy sources. Lack of public awareness about piezoelectric technology and its potential benefits may slow down its adoption.

Education and awareness campaigns could be crucial for its acceptance and integration into various industries. Excessive bureaucratic processes or regulations can pose a threat to the smooth integration and adoption of piezoelectric technology in various sectors.

4.2.2 Biofuels (see in table 4.2)

Table 4.2 SWOT Matrix of Data Analysis for Biofuels

STRENGTHS	**WEAKNESSES**
S1 Renewable Energy Source S2 Reduced Greenhouse Gas Emissions S3 Energy Security S4 Compatibility with Existing Infrastructure	W1 Land Use and Food Production Concerns W2 Energy Intensive Production Processes
OPPORTUNITIES	**THREATS**
O1 Technological Advances O2 Advanced Biofuels O3 Policy Support	T1 Competition with Food Production T2 Fluctuating Feedstock Prices T3 Low Energy Density T4 Market Competition

1) Strengths of Biofuels

Biofuels are derived from organic materials such as crops, agricultural residues, and organic waste. They are considered renewable because these sources can be replenished over time. Compared to traditional fossil fuels, biofuels produce lower net greenhouse gas emissions. This reduction in carbon emissions can contribute to mitigating climate change. Energy Security: Biofuels can be produced domestically, reducing dependence on imported fossil fuels, and enhancing energy security for countries. Compatibility with Existing Infrastructure: Biofuels can be used in existing internal combustion engines and transportation infrastructure with minimal modifications. This makes them a feasible and practical alternative to traditional fuels.

2) Weaknesses of Biofuels

The production of biofuels often requires substantial amounts of land and resources, leading to concerns about competition with food crops and potential impacts on food prices. Striking a balance between biofuel production and food production is a significant challenge. The production of some biofuels, particularly certain types of bioethanol and biodiesel, can be energy-intensive, offsetting some of the environmental benefits. Improving the efficiency of production processes is an ongoing challenge.

3) Opportunities for Biofuels

Ongoing research and technological advancements can lead to more efficient and cost-effective methods for producing biofuels, making them more competitive with traditional fossil fuels. The development of advanced biofuels, such as second-generation biofuels derived from non-food feedstocks or waste, holds promise for addressing some of the limitations associated with first-generation biofuels. Government policies and incentives that support the development and use of biofuels can create opportunities for growth in the biofuel industry. These policies may include tax incentives, subsidies, and renewable fuel standards.

4) Threats for Biofuels

The use of food crops for biofuel production can lead to competition for arable land and resources, potentially impacting global food supplies and prices. The availability and cost of biofuel feedstocks, such as crops and waste materials, can be subject to fluctuations in market conditions, weather patterns, and other factors, affecting the economic viability of biofuel production. Some biofuels have lower energy density compared to traditional fossil fuels, which can result in reduced fuel efficiency and increased fuel consumption. This could be a limiting factor in certain applications. Biofuels face competition from other renewable energy sources, such as solar and wind power. The growth of these alternative technologies may pose a threat to the widespread adoption of biofuels.

4.2.3 Solar Power (see in table 4.3)

Table 4.3 SWOT Matrix of Data Analysis for Solar Power

STRENGTHS	WEAKNESSES
S1 Abundant and cost-free resource from the sun S2 Cent percent clean process involved in converting solar energy to electricity S3 Flexibility on utility S4 Lower overall cost is an added advantage for solar power plants	W1 Uneven distribution of energy production W2 Large initial investment W3 Large space of land required. W4 Limited locations that satisfy the required amount of solar sunlight due to geographical and meteorological factors

Table 4.3 SWOT Matrix of Data Analysis for Solar Power (Con't)

STRENGTHS	WEAKNESSES
S5 Among the other options solar has the highest rating for safety S6 Low maintenance cost requirements S7 Supply chain for solar power plants ae less complicated and secure	
OPPORTUNITIES	**THREATS**
O1 Regular innovations in the field of solar energy O2 Investment opportunities for aspiring investors. O3 Job opportunities	T1 Long term return on investment T2 High per unit production cost

1) Strengths of Solar Energy

Solar energy, an abundant resource, enters the Earth at a continuous irradiance of about 173,000 terawatts, surpassing global energy consumption by 10,000 times (Energy.gov, 2016). Solar power plants, economically operating on solar energy, save transportation costs, providing a competitive advantage (Solar Energy Strengths, 2021). The conversion of solar energy into electricity involves exposing plates to the sun and utilizing photovoltaic cells. In UAE's solar plants, solar radiations are captured using parabolic troughs, converted into pressurized High-Temperature Fluid (HTF), passing through heat exchangers to produce steam. The steam powers a turbine, generating electricity connected to the grid or stored (Energy.gov, 2016). This process is emission-free, making solar one of the cleanest renewable energy methods. Solar power plants, unlike baseload power plants, are load-following and offer flexibility in generating electricity according to demand. Unused electricity is stored in the Central Tower for future use. Solar, with moderate capital costs, emerges as the cheapest renewable energy option. Its safety, derived from the fuel-free nature of its process, and lower risks with proper safety protocols ensure employee safety. Solar panels require minimal maintenance, with potential dangers identified as exposure to rains, dust, and wind. The solar supply chain encompasses products (manufacturing, cell modules, generator, module parts, and protection) and services (distribution, construction, operation, maintenance, grid connection).

2) Weaknesses of Solar Energy

Solar power plants face challenges in providing constant high energy due to factors like irradiation intensity, which varies based on the Earth's relative position to the sun. Energy generation is contingent on sunlight availability, resulting in zero production during nighttime. Seasonal variations further impact energy generation (National Energy Action (NEA), 2010). The substantial initial investment, around 43 million GBP covering 90% of the project cost over a loan term of 10 to 20 years, poses a high-risk scenario only manageable by major investing organizations and banks. In the UAE, solar parks have attracted a total capital investment of 10.7 billion GBP. Delays in planning, construction, and other phases can lead to over-expenditure, potentially exhausting invested capital without returns. Operational challenges include the need for extensive space to accommodate the large quantity of solar panels required for optimal exposure to the sun. For instance, the Sweihan Solar plant in the UAE, boasting a capacity of 1,177MW and ranking among the largest globally, covers an expansive 7.8 square kilometres, with half of the area occupied by solar panels. This reliance on direct solar irradiation for extended hours demands a specific geographical context, with the GCC region, experiencing abundant sunlight throughout the year, being more suitable than countries in Europe and the Northern Hemisphere with shorter summers and reduced sunlight hours.

3) Opportunities for Solar Energy

As the energy industry evolves, there is a continuous drive for improved technology and panels, focusing on enhancing efficiency and durability while minimizing residues. This dynamic environment presents an opportunity for the engineering field to engage in research and development, aligning systems with evolving concepts and expectations. Current advancements include the development of ultra-efficient solar cells for both small and large-scale power plants, with ongoing efforts to create panels capable of collecting energy even during nighttime (Pilkington, B., 2022). Solar power plants, requiring substantial initial investments that often cover a massive portion of project expenses, attract funding from major investing organizations or banks. This influx of capital contributes to the host country's financial statistics, encouraging smaller investors to participate, thereby boosting the country's overall finance. The development and operation of solar power plants generate job opportunities both before and after completion. Roles such as engineers, maintenance staff, cleaners, managers, technicians, and data analysts are recruited to ensure the plant's smooth operation. The pre-operation phase demands labour for construction and project management, creating a range of job opportunities. Importantly, the extended life cycle of solar power plants provides opportunities for employment across two generations.

4) Threats for Solar Energy

The construction and commissioning phases of solar power plants pose potential risks of delays, which can lead to over-expenditure without immediate returns. Incorrect project analysis may result in lower electricity generation, extending the period for return on investment and reducing overall turnover. When considering the Levelized Cost of Electricity (LCOE), solar energy exhibits a higher LCOE compared to its competitors such as wind, hydro, and natural gas. Additionally, the impact of inflation contributes to rising production costs and expenses, further elevating the relative LCOE for solar energy.

4.2.4 Wind Power (see in table 4.4)

Table 4.4 SWOT Matrix of Data Analysis for Wind Power

STRENGTHS	WEAKNESSES
S1 Abundant wind resources S2 Diversification of energy sources S3 Growing commitment to renewable energy S4 Technological advancements	W1 Intermittency W2 High initial investment W3 Land availability
OPPORTUNITIES	**THREATS**
O1 Economic diversification O2 Regional leadership O3 Technological innovation	T1 Political and regulatory uncertainties T2 Competition from other energy sources T3 Environmental considerations

1) Strengths of Wind Power

The UAE has vast areas with strong and consistent wind patterns, especially along its coastlines and in desert regions, making it suitable for wind energy generation. Investing in wind energy allows the UAE to diversify its energy mix, reducing reliance on fossil fuels and enhancing energy security. The UAE government has shown a strong commitment to renewable energy, evident through initiatives like the UAE Energy Strategy 2050, which aims to increase the share of clean energy in the country's total energy mix. Advances in wind turbine technology have made wind energy more efficient and cost-effective, making it a more viable option for electricity generation in the UAE.

2) Weaknesses of Wind Power

Wind energy production is dependent on wind availability, which can be intermittent and unpredictable. This intermittency can lead to challenges in balancing supply and demand in the grid. While the cost of wind energy has been decreasing, the initial investment required for establishing wind farms and infrastructure remains high, which may deter some investors. Finding suitable land for wind farms in the densely populated areas of the UAE, especially near urban centres, may be challenging.

3) Opportunities of Wind Power

Developing the wind energy sector presents opportunities for economic diversification, job creation, and the growth of a domestic renewable energy industry in the UAE. By investing in wind energy and becoming a leader in renewable energy in the Middle East, the UAE can enhance its regional influence and reputation as a forward-thinking nation. Investing in research and development in wind energy technologies can lead to innovations that improve efficiency, reduce costs, and address challenges specific to the UAE's environment.

4) Threats of Wind Power

Changes in government policies, regulations, or incentives related to renewable energy could impact the viability and attractiveness of wind energy investments in the UAE. Wind energy in the UAE may face competition from other sources of renewable energy, such as solar power, as well as traditional fossil fuels, which may continue to be heavily subsidized. While wind energy is considered clean and environmentally friendly, its impact on local ecosystems, wildlife, and visual landscapes should be carefully assessed and managed to avoid potential backlash from environmental groups or local communities. Overall, despite facing challenges, wind energy presents significant opportunities for the UAE to diversify its energy mix, reduce greenhouse gas emissions, and foster economic growth in the renewable energy sector.

4.2.5 Hydro Power (see in table 4.5)

Table 4.5 SWOT Matrix of Data Analysis for Hydro Power

STRENGTHS	WEAKNESSES
S1 Water storage infrastructure	W1 Limited water resources
S2 Renewable energy diversification	W2 Environmental impact
S3 Energy storage capabilities	W3 High initial investment
S4 Technological expertise	
OPPORTUNITIES	**THREATS**
O1 Renewable energy integration	T1 Regulatory challenges
O2 Potential for innovation	T2 Competition with other renewables
O3 Water-energy nexus	T3 Climate change impacts

1) Strengths of Hydro Power

The UAE has invested in water storage infrastructure such as dams and reservoirs for managing its limited water resources. These existing structures could potentially be utilized for small-scale hydroelectric projects. Incorporating hydroelectricity into the energy mix could contribute to diversifying the UAE's renewable energy portfolio, reducing dependence on fossil fuels, and enhancing energy security. Pumped-storage hydroelectricity systems can provide valuable energy storage capabilities, allowing for better integration of intermittent renewable energy sources like solar and wind power into the grid. The UAE has significant technological expertise and financial resources, which could be leveraged for the development and implementation of innovative hydroelectric projects.

2) Weaknesses of Hydro Power

The UAE faces challenges related to its scarcity of freshwater resources, which limits the feasibility and scalability of hydroelectric projects. Dependence on desalination plants for freshwater adds to the strain on water resources. Hydroelectric projects, even small-scale ones, can have environmental impacts such as habitat disruption, alteration of water flow regimes, and potential harm to aquatic ecosystems. These impacts need to be carefully evaluated and mitigated. Developing hydroelectric projects requires substantial upfront investment, particularly for construction and infrastructure development. The economic viability of such projects needs to be carefully assessed, especially given the alternative energy options available.

3) **Opportunities for Hydro Power**

Hydroelectricity can complement other renewable energy sources like solar and wind power, providing a reliable source of electricity generation that can be adjusted based on demand. Research and development efforts could focus on innovative hydroelectric technologies suited to the UAE's unique geography and water resources, such as low-impact run-of-river schemes or floating hydroelectric platforms. Integrated water and energy management approaches could be explored to maximize the efficiency and sustainability of both water and energy resources in the UAE.

4) **Threats for Hydro Power**

Developing hydroelectric projects may face regulatory hurdles related to water rights, environmental permits, and land use approvals. Uncertainties in regulatory frameworks could pose challenges for project development. Hydroelectricity in the UAE may face competition with other renewable energy sources such as solar and wind power, which may be more cost-effective or easier to implement given the country's geographic conditions. Climate change could exacerbate water scarcity and alter precipitation patterns in the UAE, affecting the availability and reliability of water resources for hydroelectric projects.

4.2.6 Geothermal (see in table 4.6)

Table 4.6 SWOT Matrix of Data Analysis for Geothermal

STRENGTHS	**WEAKNESSES**
S1 Abundant geothermal resources	W1 Geological challenges
S2 Reliable and consistent energy source	W2 High upfront costs
S3 Diversification of energy mix	W3 Water scarcity
S4 Low carbon footprint	W4 Competition with conventional fuels
OPPORTUNITIES	**THREATS**
O1 Technological advancements	T1 Resource uncertainty
O2 Synergy with other industries	T2 Market competition
O3 Government support	T3 Regulatory challenges
O4 Export potential	T4 Environmental concerns

1) Strengths of Geothermal

While the UAE is primarily known for its oil and gas reserves, it does have potential geothermal resources, particularly in the form of high-temperature geothermal reservoirs beneath the Earth's surface. Geothermal energy provides a consistent baseload power supply, unlike some other renewable energy sources such as solar and wind, which are intermittent and dependent on weather conditions. Introducing geothermal energy into the UAE's energy mix would help diversify its sources of electricity generation, reducing reliance on fossil fuels and enhancing energy security. Geothermal energy is a clean and renewable energy source that produces minimal greenhouse gas emissions, contributing to efforts to mitigate climate change and reduce carbon footprint.

2) Weaknesses of Geothermal:

The geological characteristics of the UAE may present challenges for geothermal energy extraction. Accessing deep geothermal reservoirs and drilling in the hard rock formations typical of the region could increase costs and technical complexity. Developing geothermal projects requires significant upfront investment, especially in exploration and drilling activities. The initial capital expenditure may deter some investors or necessitate government support and incentives. Geothermal power plants typically require water for steam generation and cooling purposes. Given the water scarcity in the UAE, the availability and sustainable use of water resources for geothermal projects could be a limiting factor. The UAE's abundant reserves of oil and natural gas, coupled with existing infrastructure for conventional energy production, may pose a challenge to the widespread adoption of geothermal energy.

3) Opportunities for Geothermal

Ongoing advancements in geothermal exploration, drilling techniques, and power plant technology may make geothermal energy more viable and cost-effective in the UAE. Geothermal energy extraction could potentially be integrated with other industrial activities, such as desalination or agriculture, to maximize resource utilization and create synergies. The UAE government has shown a commitment to renewable energy development through initiatives like the UAE Energy Strategy 2050. Supportive policies, incentives, and funding opportunities could facilitate the growth of the geothermal energy sector. If successfully developed, the UAE's expertise in geothermal energy technology and project management could create opportunities for exporting knowledge and services to other regions with similar geological conditions.

4) Threats for Geothermal

Despite the presence of geological indicators of geothermal potential, the actual viability and size of geothermal resources in the UAE remain uncertain until extensive exploration and drilling activities are conducted. Geothermal energy in the UAE may face stiff competition from other renewable energy sources, particularly solar and wind power, which have already gained traction and investment in the region. Uncertainties surrounding geothermal resource ownership, permitting, and regulatory frameworks could delay project development and increase risk for investors. While geothermal energy is considered environmentally friendly, there could be local environmental impacts associated with drilling activities, such as land disturbance and potential groundwater contamination, which need to be addressed through proper mitigation measures and environmental assessments.

4.2.7 Biomass (see in table 4.7)

Table 4.7 SWOT Matrix of Data Analysis for Biomass

STRENGTHS	WEAKNESSES
S1 Abundant waste resources	W1 Resource limitations
S2 Potential for energy recovery	W2 Logistical challenges
S3 Complement to renewable energy mix	W3 Technology and infrastructure gaps
S4 Local economic benefits	W4 Environmental concerns
OPPORTUNITIES	**THREATS**
O1 Waste-to-energy projects	T1 Competing land uses
O2 Biofuel production	T2 Policy and regulatory barriers
O3 Circular economy initiatives	T3 Market dynamics
O4 Research and innovation	T4 Public acceptance

1) Strengths of Biomass

The UAE generates significant quantities of organic waste, including agricultural residues, municipal solid waste, and organic by products from industries like food processing. These waste streams can serve as feedstock for biomass energy production. Biomass energy offers the opportunity to recover energy from organic waste that would otherwise be landfilled or incinerated, reducing greenhouse gas emissions, and addressing waste management challenges. Integrating biomass energy into the UAE's energy portfolio can complement other renewable energy sources like solar and wind power, providing a consistent baseload power supply. Developing biomass energy projects can create local employment opportunities, stimulate economic growth in rural areas, and support the development of a domestic bioenergy industry.

2) Weaknesses of Biomass

While organic waste resources are abundant in the UAE, their availability may be sporadic or seasonal, posing challenges for consistent biomass feedstock supply. Collecting, transporting, and processing biomass feedstock can be logistically complex and expensive, especially if the waste sources are dispersed or located far from energy facilities. The UAE may lack the necessary technology and infrastructure for efficient biomass energy conversion and utilization, requiring investment in biomass processing facilities, power plants, and grid integration. Biomass energy production may raise environmental concerns related to land use change, air emissions from combustion, and water consumption for irrigation of energy crops, necessitating careful sustainability and emissions management.

3) Opportunities for Biomass

Implementing waste-to-energy projects can help the UAE address its waste management challenges while simultaneously generating renewable electricity and heat. Biomass resources can be used to produce biofuels such as biogas, biodiesel, and bioethanol, offering opportunities to reduce dependence on fossil fuels in transportation and other sectors. Biomass energy fits within the concept of a circular economy by valorising waste streams and promoting resource efficiency, aligning with the UAE's sustainability goals. Investing in research and innovation can unlock modern technologies and processes for biomass energy conversion, improving efficiency, reducing costs, and expanding the range of feedstock options.

4) Threats for Biomass

The UAE's limited land availability and competing land uses for agriculture, urban development, and conservation may constrain the expansion of energy crop cultivation for biomass production. Inconsistent or inadequate policies, regulations, and incentives for biomass energy development could hinder investment and project implementation. Fluctuations in energy prices, competing renewable energy sources, and geopolitical factors may affect the economic viability of biomass energy projects in the UAE. Biomass energy projects may face opposition from local communities or environmental groups due to concerns about air quality, land use impacts, and odour associated with biomass processing and combustion.

Based on the analysis results shown in table 4.1 to table 4.7. Its summarize the alternative renewable energy for aviation in UAE about 7 alternative energy are (1) Piezoelectricity (2) Biofuel (3) Solar (4) Wind (5) Hydro (6) Geothermal (7) Biomass (see in table 4.8)

Table 4.8 Summarize SWOT Analysis for alternative energy

Alternative Energy	Strength Opportunities (SO)	Strength Threats (ST)	Weakness Opportunities (WO)	Weakness Threats (WT)
Piezoelectricity	- Ability to be applied in other applications due to its versatility and long-life span - Advancements in science leading to more effective and efficient materials	- Scalability issues.	- Encouraging prospects to pursue the field of renewable energy due to lack of knowledge	- Choosing other forms of renewable energy due to scalability issues - Procurement and sourcing of piezoelectric materials
Biofuel	- Evolution to more efficient and effective biofuels -Transition of existing infrastructures	-Inability to produce high energy density -Product price variations	-Unused spaces of land can be used for biofuel production	-Low energy density despite the intensive energy production process
Solar	-Development of more solar parks due to less development cost	-High dependability on the sun	-Development of technology to draw power through solar at night	-Shift in earth's position could result major radiation changes
Wind	-Spaces and resource for wind turbines -More efficient turbine for energy conversion	- Environmental changes can alter the course of wind path.	-High initial investment opens international investing opportunities	-Potential regulatory changes can lead to decommissioning of existing wind turbines.
Hydro	-Technological advancement allows energy storage	-Water storage infrastructure cannot be built in multiple locations	-Technological innovations have increased water input through artificial rains	-Backlashes of artificial rains -Least compatible with the region's climatic conditions
Geothermal	-Abundant resources pave way for more energy production	-Resource uncertainty despite abundance lead to unexpected energy output	-Water scarcity can be tackled using the water from the sea	-Preference of other alternative renewable energy
Biomass	-Abundant waste resources lead to more waste to energy projects and energy production	-Secluded land spaces for biomass and conversion facilities are limited	-Biomass can be used for biofuel production	-Environmental impacts of biomass lead to competitive energy land uses

CHAPTER 5

CONCLUSION, DISCUSSION AND RECOMMENDATIONS

This chapter covers the conclusion, discussion, and recommendations derived from the comprehensive analysis conducted throughout the research and electrical simulations. Expect a concise summary of the main contributions of the study, including the identification of best practices and the exploration of future work to the alternative renewable energy solutions for airports in the UAE. The summary of conclusion, discussion, and recommendations of this study are as follows:

5.1 CONCLUSION

In conclusion, the exploration and analysis for sustainable and alternative energy has been performed for the airports in the UAE. The piezoelectric technology displayed in the circuit design demonstrates its unique ability to convert mechanical energy into electrical energy using materials with inherent piezoelectric properties. Its minimal environmental impact, especially in airport applications, positions it as an innovative solution for harnessing energy from runway pavements during various aircraft activities. The technology is versatile, extending beyond airports to applications in public parking spaces. Despite the initial implementation costs, its minimal maintenance requirements make it economically viable.

As of 2024, according to the Global Framework for Aviation Alternative Fuels (GFAAF), there are 298 reported SAF and LCAF facilities with a combined production capacity of 79 megatons per year. Among these, more than 120 airports are actively distributing Sustainable Aviation Fuel (SAF), with 81 airports maintaining continuous deliveries and 44 receiving batch deliveries for specific flights or series of flights. A total of 39 policies have been established to promote SAF and Lower Carbon Aviation Fuel (LCAF), with 49% currently in development and 51% already adopted by respective countries. Since July 2023, 11 conversion processes for SAF production have been approved, with an additional 11 processes currently under evaluation by organizations such as ASTM International. Regarding feedstocks, 42 are officially recognized under the ICAO CORSIA framework, with ongoing assessment for the inclusion of new feedstocks in SAF production. *(ICAO. (2024))*

However, challenges such as scalability for large-scale energy production and variable efficiency highlight the need for further development. Based on the research procedure of research and simulation it can be concluded that the losses incurred during the energy conversion process, circuit components, and rectification phase emphasize the importance of continuous improvement in the circuit design. Excessive heating, a byproduct of energy loss, necessitates careful consideration of material properties to ensure long-term reliability.

The significant findings derived from the SWOT analysis, aligning with the thesis's objective, can be summarized as follows:

1) Piezoelectric: Piezoelectricity offers a renewable energy solution by utilizing the mechanical vibrations, highlighting durability, low environmental impact, and governmental support. Its versatility spans various applications, from energy harvesting to medical devices, with minimal maintenance costs. However, limitations in power generation, reliance on mechanical vibrations, and industry-related challenges, such as supplier reliability and a skilled workforce shortage, presents hurdles to widespread adoption.

Yet, opportunities arise as piezoelectric technology allows for low initial investment, especially appealing for wearable technology. Ongoing material science advancements could enhance efficiency and cost-effectiveness, expanding its applications. Upon further studying the results of SWOT analysis, it is evident that piezoelectricity consists of more strengths and shows prospect of future development. As shown from both table 3 and 10, piezoelectricity presents issues of scalability, but the simplicity of installation, usability and maintenance makes it a reliable choice for sustainable energy for airports.

2) Biofuel: Sourced from organic materials like crops and waste, offer a renewable energy alternative with lower greenhouse gas emissions. Enhancing energy security, they can be produced domestically, fitting seamlessly into existing infrastructure. However, concerns about land use and resource competition, especially with food crops, pose challenges, alongside the energy-intensive production of certain biofuels.

The future of biofuels lies in research-driven efficiency improvements, cost-effective methods, and the development of advanced alternatives like second-generation biofuels.

Government support through policies and incentives is vital for industry growth. Yet, threats emerge from potential competition for arable land, market fluctuations affecting feedstock costs, lower energy density impacting efficiency, and competition from other renewables like solar and wind power. Navigating these complexities requires strategic measures to optimize biofuels' contribution to the renewable energy landscape.

3) **Solar Energy:** Solar energy stands out as a formidable renewable resource, with an impressive continuous irradiance that surpasses global energy consumption by a significant margin. Economically efficient solar power plants, leveraging photovoltaic cells and advanced technologies like parabolic troughs, contribute to a cleaner environment with emission-free processes. Load-following capabilities and storage options make solar energy flexible and cost-effective, positioning it as the cheapest renewable option. The solar industry provides extensive job opportunities and attracts significant capital investments, contributing to a nation's financial growth.

However, challenges include the variability in energy generation due to factors like sunlight availability, seasonal changes, and substantial initial investments, presenting potential risks and operational hurdles. While opportunities lie in ongoing technological advancements and job creation, threats include project delays, incorrect analysis affecting electricity generation, and a comparatively higher LCOE impacted by inflation. Delving into these complexities requires optimal measures to benefit solar energy as an alternative renewable energy.

4) **Wind Energy:** Wind power in the UAE emerges as a promising renewable energy source, capitalizing on vast areas with consistent wind patterns, especially along coastlines and desert regions. Advances in wind turbine technology enhance the efficiency and cost-effectiveness of wind energy, making it a more viable option for electricity generation in the region.

Nevertheless, challenges arise from the intermittent and unpredictable nature of wind availability, affecting the balance of supply and demand in the grid. Opportunities lie in the economic diversification, job creation, and the growth of a domestic renewable energy industry. Strategic investments in research and development can lead to innovations that improve efficiency, reduce costs, and address unique environmental challenges in the UAE. Potential threats include changes in government policies or competition from other renewable sources like solar power and traditional fossil fuels.

5) Hydropower: Hydropower holds strategic advantages for the UAE, leveraging existing water storage infrastructure for potential small-scale hydroelectric projects. The country's technological expertise and financial resources position it well for innovative hydroelectric ventures, including pumped-storage systems that enhance energy storage capabilities and integrate intermittent renewables like solar and wind power.

However, challenges arise from the UAE's freshwater scarcity, limiting the feasibility and scalability of hydroelectric projects. Dependency on desalination plants further strains water resources, while potential environmental impacts necessitate careful evaluation and mitigation efforts. Opportunities emerge in hydroelectricity's potential to complement other renewables, offering a reliable electricity source adaptable to demand fluctuations. Research and development efforts can explore innovative technologies suited to the UAE's geography, such as low-impact run-of-river schemes or floating platforms. Integrated water and energy management approaches present avenues to optimize resource efficiency and sustainability. The competitive landscape with other renewables, such as solar and wind power, may impact hydroelectric viability. Climate change-induced shifts in water availability and reliability further add to the challenges faced by hydroelectric projects in the UAE.

6) Geothermal: Geothermal energy presents a distinctive set of strengths and challenges in the context of the UAE's energy landscape. While the country is renowned for its abundant oil and gas reserves, it harbours potential geothermal resources, specifically high-temperature reservoirs beneath the Earth's surface. Geothermal energy offers a reliable baseload power supply, countering the intermittency of solar and wind, and its integration could diversify the UAE's electricity generation sources, diminishing reliance on fossil fuels. Moreover, geothermal energy aligns with sustainability goals by producing minimal greenhouse gas emissions. However, geothermal extraction in the UAE faces geological challenges, with deep reservoir access and drilling in the region's hard rock formations posing increased costs and technical complexities. The reliance on water resources for steam generation and cooling raises concerns given the country's water scarcity. Opportunities lie in ongoing advancements in geothermal technologies, making it more economically viable. Despite that, uncertainties persist regarding the actual size and viability of geothermal resources, and competition from established renewables like solar and wind may impact its adoption.

7) Biomass: Biomass energy in the UAE leverages abundant organic waste streams, including agricultural residues and municipal solid waste, offering an environmentally beneficial solution to waste management challenges. By converting this waste into energy, the UAE can reduce greenhouse gas emissions, provide a consistent baseload power supply, and contribute to a circular economy. The potential for local employment opportunities and economic growth, particularly in rural areas, adds to the appeal of biomass energy projects.

However, challenges arise from seasonal availability of organic waste, complicating the consistent supply of biomass feedstock. Logistical complexities and expenses associated with collecting, transporting, and processing dispersed waste sources pose additional hurdles. Environmental concerns related to land use change, air emissions from combustion, and water consumption for irrigation further highlight the need for careful sustainability management. Despite these challenges, there are few opportunities such as the concept of waste-to-energy projects can address waste management issues while generating renewable electricity and biofuels. Biofuels derived from biomass offer a chance to reduce dependence on fossil fuels in transportation. Potential threats include limited land availability, fluctuations in energy prices and competition from other renewable sources that could impact the economic viability of biomass energy projects. In summary, while biomass energy presents environmental and economic advantages, careful planning and strategic initiatives are essential to address its associated complexities and challenges in the UAE. (see in figure 5.1)

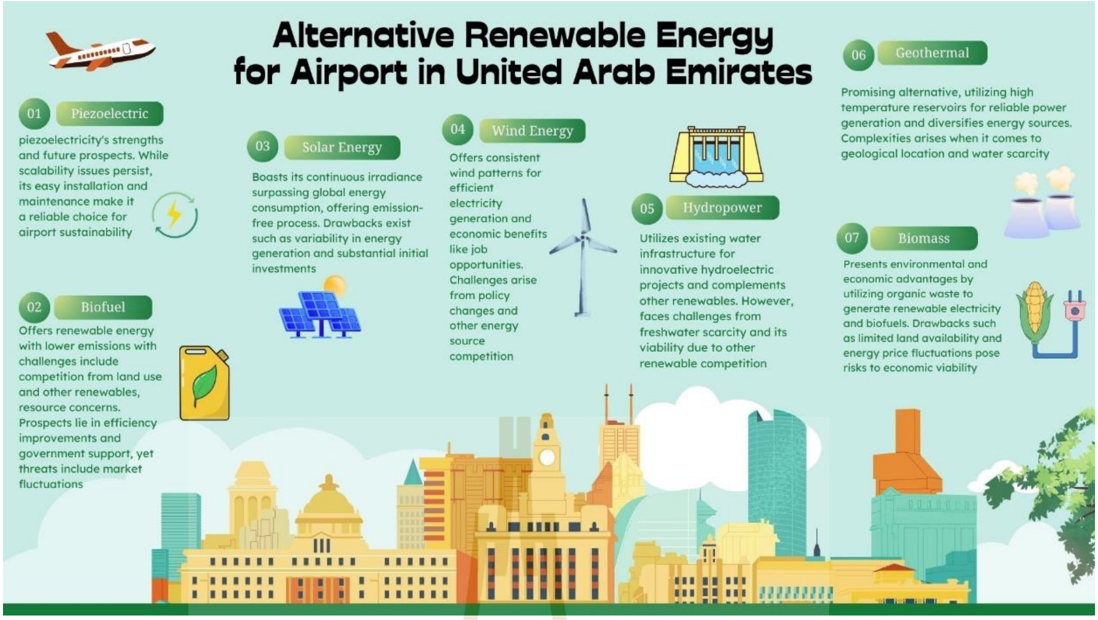

Figure 5.1 Alternative Renewable Energy for Airport in UAE

5.2 DISCUSSION

The distinctive feature of piezoelectric technology lies in its ability to transform mechanical energy into electrical energy using materials with inherent piezoelectric properties, such as quartz or ceramics. This technology maintains a minimal environmental impact, avoiding combustion processes or the use of chemicals. Leveraging mechanical stress or vibration, piezoelectric systems can be seamlessly incorporated into runway pavements to generate electricity during an aircraft's taxiing, take-off, landing, or parking. This is not limited to airports; it can also be implemented in public parking spaces. While well-suited for small-scale applications like sensors and integration into structures such as road or runway lights, the initial implementation costs for a piezoelectric circuit in runway pavements may be substantial, offset by modest maintenance expenses. However, challenges exist, including the scalability of piezoelectric pavements for large-scale energy production and variable efficiency, influenced by factors like the intensity and consistency of mechanical stress or vibration, as well as the efficacy of the conversion materials.

In the piezoelectric circuit design, there can be several types of losses, which involves the inherent losses process of converting mechanical energy to electrical energy in the piezoelectric material. This also includes electrical losses due to resistance in the circuit components and leakage currents as it travels through the circuit, therefore resulting in a significant impact in the circuits performance. During the rectification phase, the full bridge rectifier does introduce losses during the conversion of AC to DC. This is due to the diodes in the rectifier, resulting in voltage drops and power losses. Furthermore, it can decrease the efficiency of the circuit as each component in the circuit, including the piezoelectric material, diodes, and regulator, has its own efficiency and may introduce losses. Increased heating may occur within the electrical circuit when electrical energy is lost as heat, which can lead to rise in temperature of the piezoelectric material. Depending on the material, excessive heating can lead to thermal stress and degradation of the material, affecting its long-term reliability and performance.

Comparatively, while other alternatives like Biofuel, Solar Energy, Wind Energy, Hydropower, Geothermal, and Biomass highlight commendable attributes, each comes with its set of challenges. Biofuels, for instance, presents concerns regarding land use competition and energy-intensive production. Solar Energy, while economically efficient, contends with variability and substantial initial investments. Wind Energy, despite capitalizing on consistent wind patterns, faces intermittency challenges. Hydropower encounters freshwater scarcity issues and potential environmental impacts.

In the context of these challenges and strengths, Piezoelectricity stands out as a viable option due to its minimal environmental impact, government support, and potential for advancements in efficiency and cost-effectiveness. The technology's adaptability to various applications, particularly in airports, and its simplicity of installation make it a reliable choice.

While the results are promising, it is essential to address certain challenges. These include the development of exceptionally durable piezoelectric materials capable of withstanding heavy loads, scalability, optimizing the energy conversion efficiency, and establishing reliable storage and distribution mechanisms for the harvested energy.

5.3 RECOMMENDATION

To drive sustainable energy initiatives in the UAE, it is crucial for organizations to invest in research and development aimed at enhancing piezoelectric technology. Prioritizing advancements in durable materials will improve the longevity and resilience of piezoelectric systems, ensuring they withstand heavy loads, loading with low frequency and diverse weather conditions. Simultaneously, a focus on optimizing energy conversion efficiency is important, particularly during key aircraft movements such as taxiing, take-off, and landing. Organizations should collaborate with research institutions to explore and develop superior piezoelectric materials, fostering innovation in infrastructure integration such as runway pavements.

For society, embracing and implementing advanced piezoelectric technology would signify a commitment to environmentally friendly energy solutions. The reduction of greenhouse gas emissions associated with traditional energy sources aligns with global Net Zero goals. Moreover, the integration of piezoelectric systems in public spaces, such as airports and urban infrastructure such as parking spaces, not only generates clean energy but also promotes public awareness of renewable energy.

The adoption of enhanced piezoelectric technology can position the UAE as a leader in sustainable renewable energy in the aviation sector. This investment aligns with the country's commitment to reducing carbon emissions and diversifying its energy portfolio. Government support, both financially and through policy frameworks, is pivotal to incentivize organizations to engage in piezoelectric research and implementation. The successful integration of piezoelectric systems not only supports the UAE's sustainability but also results in a significant economic growth of the country.

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