RENEWABLE ENERGY FOR AVIATION:

PRACTICAL APPLICATIONS TO ACHIEVE CARBON REDUCTIONS AND COST SAVINGS

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PREFACE

The International Civil Aviation Organization (ICAO) and its Member States are working together to develop State Action Plans to Reduce CO_2 Emissions from International Aviation. The development and completion of States' Action Plans on CO_2 emissions reduction activities from international aviation requires the establishment of a structured cooperation process amongst national aviation stakeholders which aims to provide the State authority with the information it needs to set-up a long-term strategy for the mitigation of international aviation CO_2 emissions. The voluntary submission of an action plan to ICAO provides the opportunity for States to showcase policies and actions, including tailor-made measures that are selected on the basis of their respective national capacities and circumstances.

Many Member States, particularly Developing States and Small Island Developing States (SIDS), continue to investigate the institutional and financial resources necessary to develop and implement their action plans, and the actions therein. For example, many States, through their civil aviation authorities, are beginning to integrate environmental programmes into their planning and development, and these need to be coordinated with other government agencies. Some States also endeavour to establish or improve the national regulatory and policy frameworks necessary to encourage low carbon technology deployment, which is critical to stimulating private sector market activity. Others would also like to benefit from low carbon technologies that are being successfully developed in other parts of the world. This means that the State Action Plan initiative can be key to States developing coordinated activities aimed at reducing CO_2 emissions from international civil aviation.

ICAO has developed Doc 9988, *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities,* which aims to support Member States as they develop and implement their Action Plans. As of November 2017, 105 States representing more than 90.1 per cent of global revenue tonne kilometres (RTK) have voluntarily submitted their Action Plans to ICAO. Doc 9988 presents the basket of measures that Member States can consider for reducing CO_2 emissions from civil aviation. One important opportunity for ICAO Member States to achieve their environmental and carbon emissions reduction objectives is through the use of renewable energy.

The purpose of this guidance is to inform ICAO Member States on how renewable energy can be deployed to reduce CO_2 emissions from international aviation activities. It provides States with an introduction to how energy is consumed during aviation activities, existing renewable energy technologies and their use, issues to consider in project conceptualization, options for financing project development, the fundamental steps for planning and developing a renewable energy project, and a summary of several project examples from existing airports worldwide. While ICAO's focus is on international aviation CO_2 reduction activities, developing airport renewable energy projects can also minimize CO_2 from many energy consuming activities at airports beyond those that relate to international civil aviation. Renewable energy can also be a key component of facility modernization and economic development.

Together with guidance documents on *Sustainable Aviation Fuels, Financing Aviation Emissions Reductions*, and *Regulatory and Organizational Framework to Address Aviation Emissions*, this guidance on renewable energy will contribute to ICAO's comprehensive approach to support its Member States in the implementation of their Action Plans in order to address CO_2 emissions from international civil aviation.

LIST OF ACRONYMS AND SYMBOLS

AC	Alternating Current
ACA	Airport Carbon Accreditation
ACRP	Airport Cooperative Research Program
ACSA	Airports Company of South Africa
APU	Auxiliary Power Unit
ATM	Air Traffic Management
CAA	Civil aviation authority
CDM	Clean Development Mechanism
CNG	Compressed Natural Gas
CNS	Communication, Navigation, and Surveillance
CO_2	Carbon Dioxide
CSP	Concentrating Solar Power
DC	Direct Current
EIA	Energy Information Administration
EMS	Energy Management System
EPC	Engineering Procurement and Construction
EU	European Union
FAA	Federal Aviation Administration
FIT	Feed-in Tariff
GEF	Global Environment Facility
GHG	Greenhouse Gas
GNWT	Northwest Territories Provincial Government (Canada)
GPU	Ground Power Unit
GSE	Ground Support Equipment
GWh	GigaWatt hour
HVAC	Heating Ventilation and Air Conditioning
Hz	Hertz, a unit of frequency as in classifying electrical currents
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
kW	Kilowatt
LEED	Leadership in Energy and Environmental Design
MAG	Manchester Airports Group
MW	Megawatt
NOAA	National Oceanographic and Atmospheric Administration
PCA	Pre-conditioned Air
PCC	Point of Common Coupling
PPA	Power Purchase Agreement
PPM	Parts per million
PV	Photovoltaic
RPK	Revenue Passenger Kilometre
RTK	Revenue Tonne Kilometre
SARPs	Standards and Recommended Practices
SGHAT	Solar Glare Hazard Analysis Tool
SIDS	Small Island Developing States
TWh	Terawatt Hour
UNDP	United National Development Programme
WTG	Wind Turbine Generator

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BACKGROUND

The 39th Session of the ICAO Assembly, held from 27 September to 7 October 2016, adopted Resolution A39-2: *Consolidated statement of continuing ICAO policies and practices related to environmental protection — Climate change*. Resolution A39-2 reflects the determination of ICAO's Member States to provide continuous leadership to international civil aviation in limiting or reducing its emissions that contribute to global climate change.

The 39th Session of the ICAO Assembly reiterated the global aspirational goals for the international aviation sector of improving fuel efficiency by 2 per cent per annum and keeping the net carbon emissions from 2020 at the same level, as established at the 37th Assembly in 2010, and recognized the work being undertaken to explore a long-term global aspirational goal for international aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement. The 39th Assembly also recognized that the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions contribution to climate change, and that goals of more ambition are needed to deliver a sustainable path for aviation. To achieve international aviation's global aspirational goals, a comprehensive approach, consisting of a basket of measures has been identified, namely:

- *Aircraft-related technology development* – purchase of new aircraft and new equipment to retrofit existing aircraft with more fuel-efficient technology.
- *Alternative fuels* – investments in the development and deployment of sustainable aviation fuels.
- *Improved air traffic management and infrastructure use* – improved use of communication, navigation and surveillance/air transport management (CNS/ATM) to reduce fuel burn.
- *Economic/market-based measures* – researching and building awareness of low cost, market-based measures to reducing emissions such as emission trading, levies, and off-setting.

All of these measures, in addition to contributing to carbon neutral growth, advance the social and economic development associated with the UN Sustainable Development Goals (SDGs).

A central element of Resolution A39-2 is for States to voluntarily prepare and submit action plans to ICAO. It also lays out an ambitious work programme for capacity building and assistance to States in the development and implementation of their action plans to reduce emissions, which States were initially invited to submit by the 37th Session of the ICAO Assembly in October 2010, and update every three years thereafter. ICAO State Action Plans provide the opportunity for States to showcase policies and actions and are intended to be individualized and reflect the specific national circumstances of each ICAO Member State and the opportunities available to them in implementing measures to mitigate CO_2 emissions from international aviation activities. ICAO has prepared ICAO Doc 9988, *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities* to describe the process of developing or updating an action plan. As of November 2017, 105 Member States, representing 90.1 per cent of global RTK have voluntarily submitted their action plan to ICAO.

This renewable energy guidance has been prepared to help ICAO Member States plan and develop renewable energy projects to help limit or reduce the impact of international civil aviation CO_2 emissions on the global climate. It is part of a series of guidance documents developed as part of the capacity-building and assistance project implemented by ICAO, in cooperation with the United Nations Development Programme (UNDP), with financing from the Global Environment Facility (GEF). The primary focus of this assistance project is on identifying and facilitating the implementation of measures to reduce CO_2 emissions from international civil aviation.

With the support of GEF and UNDP, ICAO is working with SIDS and Developing States to strengthen their national capacities and improve national processes and mechanisms for the reduction of aviation emissions by:

- improving understanding of the costs and environmental benefits associated with implementation of various mitigation measures for international aviation emissions;
- enhancing policy frameworks through a series of policy instruments, including the development of guidance documents;
- sharing knowledge and resources through an integrated environmental portal, as well as other awareness-raising initiatives; and
- developing Pilot Projects, such as the installation of solar technology at airports, thus equipping Developing States and SIDS with tools to carry out similar projects and multiplying their environmental benefits.

1.0 INTRODUCTION

Climate change presents a significant challenge to international aviation due to anticipated growth in the aviation sector, the potential energy demand and carbon emission associated with that growth, if unmitigated. This chapter provides an overview of energy use and climate change, opportunities for the aviation sector to minimize impacts, and ICAO activities to support action by States to reduce fossil fuel energy use in the aviation sector.

1.1 ENERGY AND CLIMATE CHANGE

Energy is fundamental to advancing economic development and increasing living standards. The majority of energy consumed for electricity, heating and cooling, and transportation is provided by the combustion of fossil fuels.

Worldwide energy generation by source for 2012 is listed in **Table 1-1**.[1] The largest amount of electricity generation is supplied by fossil fuel fired power plants. The types of fossil fuels that can be combusted to generate electricity include coal, oil, and natural gas. Nuclear and hydroelectric power also serve significant percentages of the world consumption at 11 per cent and 17 per cent respectively.

TABLE 1-1
World electricity generation (source: US Energy Information Agency)

Generation Type	Amount (Billions of kWh)	Percentage
Fossil Fuels	14,793	67%
Hydroelectric	3,761	17%
Nuclear	2,364	11%
Renewables (non-hydro)	1,273	5%
TOTAL	**22,165**	**100%**

The total amount of electricity generated from renewable sources in 2014 was 5,294 terawatt hours (TWh).[2] This amount was approximately 22 per cent of the total global electricity production.[3] Hydropower accounted for almost three-quarters (74 per cent) of the total with wind providing 13 per cent, bioenergy 8 per cent, solar 4 per cent, and geothermal 1 per cent.[4] The non-hydro renewables accounted for approximately 6 per cent of the global total.[5] Between 2013 and 2014, solar was the fastest growing technology growing worldwide by 39 per cent, followed by wind at 12 per cent, geothermal at 7 per cent and bioenergy and hydropower at 3 per cent. Renewable energy used for electricity is spread throughout the world as shown in **Table 1-2**.[6]

The 5,294 TWh of renewable electricity is equivalent to:[7]

- Greenhouse gas emissions (GHG) from 785,893,684 automobiles
- 549,393,996 homes consuming electricity for one year
- 8,613,735,094 barrels of oil consumed
- Carbon sequestered from 3,521,837,479 acres of forest land

Region	Technologies					
	Hydro	Wind	Bioenergy	Solar	Geothermal	Total
Africa	118	5	2	2	3	131
Asia	1,520	198	85	62	23	1,888
Central America + Caribbean	24	3	4	<1	4	35
Eurasia	239	9	1	<1	3	252
Europe	595	258	170	99	11	1,133
Middle East	26	<1	<1	<1	<1	28
North America	683	213	77	27	25	1,024
Oceania	44	13	4	5	8	74
South America	658	16	55	1	<1	730
World TOTAL	**3,907**	**714**	**399**	**197**	**77**	**5,294**

TABLE 1-2
World renewable energy generation by region in 2014 (TWh)
(source: IRENA)

The global renewable energy industry has grown significantly in recent years (see **Figure 1-1**). According to the International Renewable Energy Agency (IRENA), renewable energy capacity in MWs installed has more than doubled in ten years (2007-2016).[8] Wind and solar power technologies have increased in efficiency and decreased in costs as unit production has been scaled up. In its 2016 Medium-Term Report on Renewable Energy, the International Energy Agency (IEA) stated that renewable power accounted for more than half of the world's additional electricity capacity in 2015 as the result of supportive government policies and sharp cost reductions.[9] Renewable energy is being adopted by governments and private industry, which can benefit from the long-term cost savings of a fuel-free technology and the environmental improvements sought by society. Pioneering airports have been participating in this growth and provide useful examples and lessons learned of how renewable energy projects can be implemented successfully at airports around the globe.

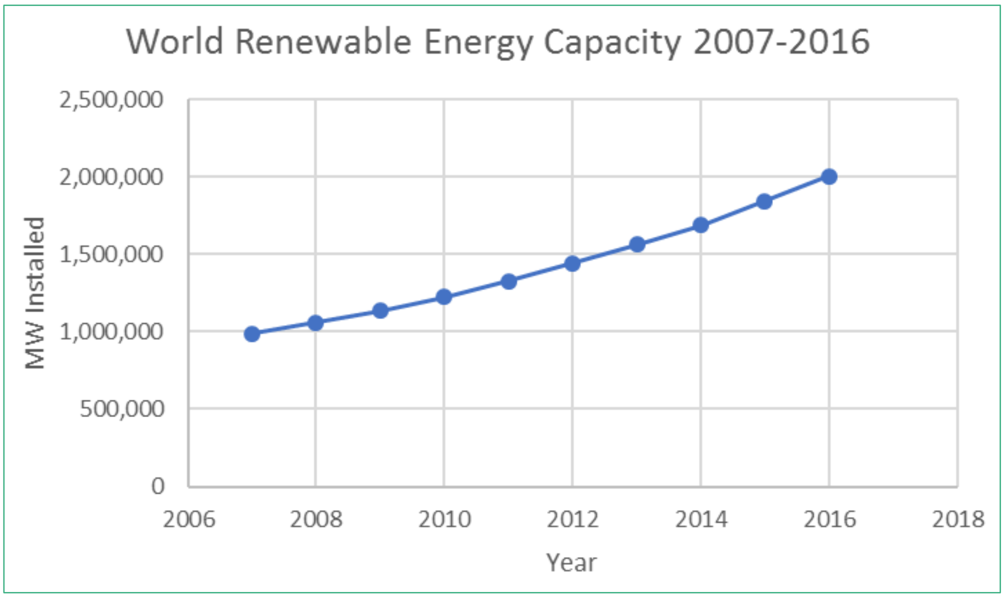

FIGURE 1-1
Growth in world renewable energy capacity
(source: IRENA)

1.2 AVIATION ENERGY REDUCTION OPPORTUNITIES

Aviation sector energy usage can be categorized as aircraft and airport operations. Emissions from domestic flights and from airport operations are under the authority of each Member State. Emissions from international flights fall under the responsibility of ICAO.

1.2.1 AIRCRAFT ENERGY

Aircraft energy is required by the aircraft through all phases of operations. Energy used by the aircraft is traditionally derived from jet fuel. Means to reduce the use of jet fuel and CO_2 emissions, which are contained in the basket of measures identified by ICAO, include improvements related to technology and operations.

Opportunities to reduce the amount of jet fuel used, and thus decrease CO_2 emissions include more fuel efficient aircraft technology, more direct flight patterns and aircraft movements throughout the flight cycle, and improved use of CNS/ATM systems. Elimination of conventional aviation fuel use through replacement can be accomplished with sustainable aviation fuels, and conversion of jet fuel powered functions on the ground to electrification. It is in this latter area where renewable energy can be used to reduce international aviation emissions through gate electrification and renewable energy. In addition, renewable energy stored in a battery used in electric taxiing equipment represents a similar opportunity.

When at the gate, aircraft typically power on-board systems with an auxiliary power unit (APU) located in the tail of the aircraft. The APU is powered with jet fuel which, when parked at the gate, powers aircraft systems and controls temperature in the cabin. As aircraft turn-around time can be 1 to 3 hours, this is a source of emissions worth considering. Many airports are now retrofitting their gates with pre-conditioned air units and 400 Hz power converters which allow the aircraft to turn off its engine and receive electrical power and heating/cooling from the airport terminal. While "electrification" of the gate eliminates on-airport emissions, the carbon emissions offset can only be confirmed when demonstrating that the electricity is supplied from a carbon free source. A renewable energy supply (e.g. from photovoltaic panels) coupled with a gate electrification system can eliminate emissions associated with the APU usage.

1.2.2 AIRPORT ENERGY

There are other energy uses associated with the airport that result in CO_2 emissions. These include a significant amount of energy for lighting within the airport buildings, heating, cooling, and information technology. A survey of airports in the United States showed that energy was the second largest expense at airports after the costs of personnel.[10] The energy uses associated with an airport also includes the fuel necessary to power ground support equipment (GSE). As ICAO Member States and airport authorities plan for improvements to meet goals for the reduction of international aviation emissions, they can also consider improvements that will reduce domestic emissions from aviation facilities. Many of these improvements will not only benefit the environment, but can also benefit business by reducing expenses, which can be reinvested elsewhere into the airport infrastructure or used to cut fees for tenants.

The development of renewable energy projects to minimize emissions from airport operations can be conducted in association with a solar at-gate project to reduce international aviation emissions, or as a separate project focused on airport emissions. The solar electricity generating facility developed with the gate equipment could be augmented in size to provide electricity not only to power the aircraft, but also to provide clean, emissions-free electricity to other functions in the terminal. Excess power could also be stored in a battery for use in electric taxiing, to power electric GSE, or for building functions with high demand on days with low light and when solar electricity is not being generated. In addition to electricity, renewable thermal projects may be developed to reduce CO_2 emissions from the heating and cooling of airport buildings.

Many parties operate at airports besides the civil aviation authority and airport authority, including airlines, gate operators, and tourism companies. Successful emissions reduction efforts require cooperation among these various parties.

1.3 PARTIES INVOLVED WITH AVIATION ENERGY REDUCTION

The main parties cooperating to reduce energy usage and associated CO_2 emissions from international aviation activities include the State (typically the civil aviation authority), airport authorities, tenants, and ICAO.

1.3.1 CIVIL AVIATION AUTHORITY

As the national authority responsible for aviation activity, the civil aviation authority should serve as the agency that provides leadership and guidance to all airport authorities, and through them to all aviation stakeholders, to establish clear and consistent rules for CO_2 emissions reductions at the airport. Its guidance is provided within the context of its responsibilities for ensuring that aviation activities are conducted in a secure, safe and efficient manner.

The civil aviation authority is responsible for implementing aviation policies and procedures that are consistent with international agreements including those established for CO_2 emissions reductions. It works closely with other authorities within their State to establish Standards, policies and to implement measures to reduce CO_2 emissions from aviation.

When considering renewable energy projects at airports, the civil aviation authority could participate in technical assistance programmes to build their internal capacity for evaluating opportunities and renewable energy resources appropriate to the specific conditions of the State. They could then coordinate with the airport authority to assess particular opportunities at each airport. Finally, they could list favourable options for future consideration in the State Action Plan.

As airports are transportation hubs used by a wide array of people, they are excellent locations to showcase the aspirations of a State. This can be seen at many airports where billboards highlight the local and national attractions that can be seen or industries promote their activities and new products. Renewable energy has been deployed by many airports around the world not only to serve the functional benefits of providing electricity, but also to communicate to visitors the progress and innovation of the country. Civil aviation authorities can ensure that renewable energy projects developed at airports are communicated to the public and promote the advance actions being taken to limit the impacts of climate change.

1.3.2 AIRPORT AUTHORITY

The airport authority, as the operator of the airport, is most knowledgeable about the day-to-day operations of the airport. It is responsible for coordinating with the State on the implementation of policies and Standards that ensure the safe and efficient operation of the airport, including those associated with CO_2 emission reduction measures. It works with airport tenants and suppliers to make sure that goods and services can be provided to customers, while maintaining the requirements of national aviation policy. The airport authority plays a crucial role, as it needs to ensure that broad policies and specific projects are consistent with the airport's mission.

As a liaison between national policy and the businesses operating at the airport, it is important for the airport authority to develop its capacity to plan and implement national environmental programmes. It should work with the State as one of the stakeholders that contribute to the development of the State Action Plan and how it can most effectively be implemented given the daily operations of the airport. In doing so, it will be required to learn new skills, such as using systems to account for CO_2 emissions at the airport and reporting the data to the State (e.g. the civil aviation authority).

In the area of renewable energy, the airport authority will need to initially build its capacity to understand the types of technologies that can be deployed at airports by learning from other initiatives around the world. Important considerations for the airport authority are how these projects could be applied to airports and how to introduce them into the airport master plan, how they can be financed, and operational and maintenance needs and programmes. Renewable energy can improve the airport's energy supply reliability and decrease energy costs over time improving the airport authority's capacity to attract credible business partners and provide enhanced services to its customers.

1.3.3 AIRPORT PARTNERS

While the airport and the State are responsible for the safe, secure, and efficient operation of the airport, they must work with many partners, such as airlines, to ensure that they are able to accomplish this work successfully. Many of these partners, and some new ones, also have a role in the airport renewable energy project.

Airlines and other tenants will have an interest in the airport's future development plans, including a proposed renewable energy project, for a number of reasons. They will want to know if the project will alter their current operations or if it will impact (positively or negatively) their business costs. As an example, a solar at-gate project will require the airline to switch its energy needs at the gate from the APU powered by jet fuel to electricity that is supplied by the airport. The airline will now need to purchase the electricity from the airport and evaluate the difference in costs to its operations.
It may have also received services from a gate operator that are no longer needed, requiring changes to existing contracts and other agreements.

Existing and new energy partners will likely have expanded roles when a renewable energy project is developed at an airport. An energy company that helps design and develop a renewable energy project may be a new partner with a central and unique role in project development, operations and maintenance. The regional or national utility company will also work with the airport to understand how a renewable energy project would interconnect with the national grid and if changes to existing power purchase tariffs are necessary to ensure consistency with power procurement and management policies. The airport will also work with environmental and economic development stakeholders to communicate the benefits of the project.

1.3.4 ICAO

ICAO facilitates the work of its Member States in developing Standards and Recommend Practices (SARPs) and guidance material aimed at reducing CO_2 emissions from international aviation, and by assisting to build local capacity for planning and implementing emission reduction projects. Member States have adopted aspirational goals to improve fuel efficiency by 2 per cent annually and to achieve carbon neutral growth from 2020. ICAO has since been working with Member States to implement programmes to achieve such emission reduction goals.

In addition, ICAO develops guidance, such as Doc 9988 *Guidance on the Development of States' Action Plans on CO_2 Emissions Reduction Activities*, to help Member States prepare State Action Plans. It works with its Member States and nominated national focal points to disseminate it through workshops and other capacity building mechanisms. As of November 2017, 105 States representing 90.1 per cent of international RTK have voluntarily submitted their Action Plans to ICAO. Doc 9988 presents a basket of measures that Member States can consider for reducing CO_2 emissions from international civil aviation. One measure that represents an important opportunity for ICAO Member States to achieve its objectives is renewable energy.

ICAO also seeks partnerships with other entities with complementary objectives of reducing emissions. These partners include, for example, the UNDP and GEF, as well as the European Union, which are supporting the development of guidance, implementation of capacity building, and demonstration of measures through pilot projects focused in ICAO Member States that are most in need of support. Through these partnerships, ICAO is building on the foundation of supporting Member States with the development of State Action Plans and the implementation of the projects identified therein.

1.4 ICAO-UNDP ASSISTANCE PROJECT

ICAO and the UNDP, with support from the GEF, are implementing the assistance project *Transforming the Global Aviation Sector: Emissions Reductions from International Aviation*. The primary project objective is to support capacity building in developing States and SIDS for reducing CO_2 emissions from international civil aviation. Its implementation will establish a framework that allows the international civil aviation sector in developing States and SIDS to fully engage in low emissions aviation and fulfil their GHG emissions reduction potential.

The project is comprised of four components:

1) identification of aviation low emissions measures in developing States and SIDS;
2) support to developing States and SIDS to strengthen their national capacities and to improve their national processes and mechanisms for the reduction of aviation emissions;
3) establishment of a technical support platform for the implementation of aviation low emissions measures; and
4) demonstration of low emissions aviation measures in developing States and SIDS, specifically the implementation of a renewable energy pilot project for aviation that can be replicated by other States.

Renewable energy is an important component of the ICAO-UNDP assistance project.

1.4.1 DEVELOPING PRACTICAL GUIDANCE

As part of the capacity building objectives of the ICAO-UNDP assistance project, four guidance documents are being prepared on:

- renewable energy;
- sustainable aviation fuels;
- regulatory and organizational frameworks; and
- financing opportunities.

The renewable energy and sustainable aviation fuels guidance documents will provide Member States with specific information on two technical measures that they might consider implementing as part of their State Action Plans. The regulatory and financing guidance documents are intended to provide Member States with a broader level of support for establishing an in-country framework for pursuing regulatory and organizational modifications to support the implementation of emission reduction measures, as well as the financing opportunities to fund different measures in the basket.

The renewable energy guidance, contained herein, is intended to provide a summary of various sources of renewable energy that could be used at airports, review environmental, financial, business, and public benefits that result from use of renewable energy at airports, and provide guidelines to developing States and SIDS on the implementation of renewable energy projects at airports.

The sustainable aviation fuel guidance provides current and consistent information on the development of sustainable aviation fuels to all ICAO Member States. It includes sections on types of feedstock used in sustainable aviation fuels production, components and steps in the supply chain, and relevant economic factors. The document provides concrete recommendations for developing States and SIDS on the use of sustainable aviation fuels.

The guidance on regulatory and organizational frameworks helps developing States and SIDS identify nationally appropriate regulatory and organizational improvements to promote the establishment of a low emissions aviation system. It provides concrete recommendations for the development of relevant national legislation, as well as proposes structures and mechanisms to oversee its implementation.

The financing guidance presents guidelines, best practices and policy recommendations on how to identify and access various possible sources of financing, including self-financing, to implement States' international aviation emissions reduction activities, including energy efficiency and renewable energies projects.

1.4.2 LAUNCHING THE SOLAR AT-GATE DEMONSTRATION PROJECT

Another important component of the ICAO-UNDP assistance project is the implementation of an emissions reduction demonstration project consistent with the UN Clean Development Mechanism (CDM) Small-scale methodology "Solar Power for Domestic Aircraft At-Gate Operations."[11] The purpose of the demonstration project is to show how a specific low emission reduction measure can be successively implemented at an international airport in a developing State or SIDS. When the project is completed, the process, lessons learned and ongoing data collection can be disseminated to Member States for replication, where applicable.

The demonstration project identified for implementation is the replacement of existing fossil fuel-powered gate equipment with new electric units powered by a solar photovoltaic (PV) facility referred to as the "solar at-gate" project. Under current conditions, the aircraft parks at the gate and all of the electricity required to power lights, on-board electronics, and cabin climate control is provided by the aircraft's APU, which is powered by jet fuel in the rear of the aircraft. In addition, mobile diesel-powered ground power units (GPU) may also be used to provide enhanced power. Some airports have already been equipping jet bridges with pre-conditioned air (PCA) units that connect the aircraft to the airport terminal's conditioning system, and installing 400 Hz GPU converters which enables delivery of electricity from the airport's electrical system to the aircraft. This retrofit is often referred to as "gate electrification". Making these improvements removes the fossil fuel emission sources and replaces them with electricity. The next step in the clean energy approach is combining gate electrification with a solar power system sized to generate the electricity required to power the aircraft when it is parked at the gate. By sizing the solar project to meet the aircraft's electricity load and incorporating meters to validate that the solar power is being consumed at the airport, the project will demonstrate the elimination of carbon intensive gate power and replacement with at-gate solar power. **Figure 1-2** provides an illustration of the project components.

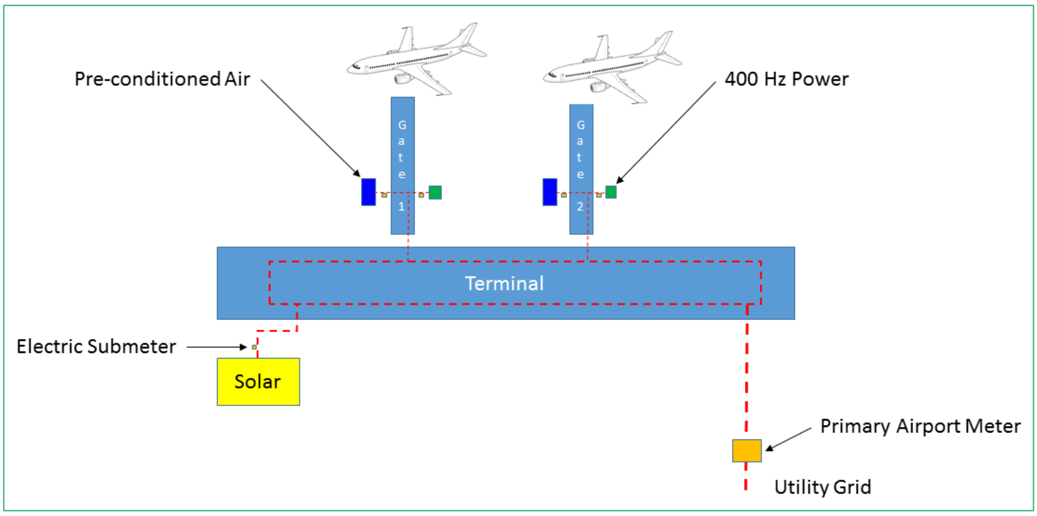

FIGURE 1-2
An example of a solar powered gate project scheme for a terminal with two gates (source: author)

Two international airports in Jamaica have been selected to demonstrate this emission reduction package as part of the ICAO-UNDP Project. At Norman Manley International Airport in Kingston, UNDP will fund the development of a 100 kilowatt (kW) solar PV system and an electrified gate comprised of a PCA unit and a 400 Hz GPU converter. At the Donald Sangster International Airport in Montego Bay, UNDP will fund the electrified gate components while also working with airport officials to explore different approaches by identifying alternative funding for the solar component, including a potential public-private partnership, or funding through a forthcoming UNDP Project. The pilot project is anticipated to be constructed and operational in early 2018.

The project is designed to be compatible with and demonstrate the benefits of the CDM small-scale methodology, "Solar Power for Domestic Aircraft At-Gate Operations."[12] While configured to serve international aircraft where possible, in reality, the project will eliminate all carbon emissions associated with aircraft gate activity regardless of the eventual destination of the aircraft. The accounting of CO_2 benefits will reflect the full value (international and domestic) of CO_2 reductions.

1.5 ICAO-EUROPEAN UNION (EU) ASSISTANCE PROJECT

ICAO is also working on a similar project with the European Union referred to as the ICAO-EU assistance project, *Capacity Building for CO_2 Mitigation from International Aviation*. The project objective is to provide assistance to a selected group of 14 States in Africa and the Caribbean to support their efforts in developing and implementing their action plans on CO_2 emissions reductions from international aviation, to establish aviation environmental systems for emissions monitoring at the State level, and to identify, evaluate and implement mitigation measures in selected States.

1.5.1 STATE ACTION PLAN SUPPORT

The ICAO-EU assistance project has supported the establishment of National Action Plan Teams in the 14 selected States, which have become a key coordination mechanism and an inclusive process for the development of Action Plans. The National Action Plan Teams are developing new strategies for working on aviation environmental issues. They coordinate with other national stakeholders (i.e. civil aviation authorities, ministries of environment, ministries of transport, airports, airlines, air navigation services providers and fuel suppliers), facilitating the decision-making process and securing the financial and political support for the implementation of mitigation measures. The project's capacity building strategy has increased awareness of aviation environmental issues, allowing national aviation organizations to assume responsibility for identifying and implementing improvements. All 14 of the participating Member States in the project have prepared action plans with assistance from the ICAO-EU Project.

1.5.2 AVIATION ENVIRONMENTAL SYSTEMS

The ICAO-EU project has also established an efficient CO_2 emissions monitoring system to facilitate the preparation of robust emissions inventories by the civil aviation authority and the periodic reporting to ICAO of CO_2 emissions from international aviation. The Aviation Environmental System (AES) was installed in the 14 States participating in the project in 2015 and 2016 through on-site missions and several capacity building activities. The operationalization and training phases are still ongoing, allowing the States to collect increasingly more data from their national airlines and to submit to ICAO their monthly CO_2 reports generated directly from the AES.

1.5.3 MITIGATION MEASURES

ICAO has selected specific projects identified in the State Action Plan for implementation. These include conducting feasibility studies of potential projects to assess the further development and actual implementation of projects. ICAO is using the funding available from the ICAO-EU project for these efforts and is coordinating with other potential partners who may be interested in participating.

Implementation projects include continuous climb operations (CCO) and continuous descent operations (CDO) in Burkina Faso and Gabon, and solar at-gate demonstration projects in Cameroon and Kenya. Feasibility studies that have also been selected include sustainable aviation fuel feasibility studies in Burkina Faso, Dominican Republic, Kenya and Trinidad and Tobago, and a renewable energy project in Trinidad and Tobago.

1.5.4 SOLAR AT-GATE DEMONSTRATION PROJECTS

The ICAO-EU Assistance Project is also demonstrating the implementation of the solar at-gate emission reduction method, consistent with the CDM Small-scale methodology "Solar Power For Domestic At-Gate Operations." [13] It is developing projects at Douala International Airport in Douala, Cameroon and Moi International Airport in Mombasa, Kenya. Both projects include solar and gate electrification, but each project demonstrates different types of project development.

In Douala, Cameroon, the French Government has already funded a project to renovate the terminal at Douala International Airport, which will include new gates with the gate electrification equipment necessary for aircraft to obtain power from the terminal instead of running the APU. The ICAO-EU assistance project is supporting the design and construction of a solar PV facility to generate electricity for the gates. In addition, the solar PV project is being sized at a maximum capacity of about 1 MW, which is more than enough electricity to power the entire airport, resulting in emission reductions beyond those associated with international aviation emissions.

In Mombasa, Kenya, the project includes a 500 kW solar project, a PCA and a GPU necessary to provide terminal electrical power to the aircraft. However, the project also includes a battery storage system to ensure that aircraft never lose power when connected to the terminal as a result of a grid outage, which can significantly disrupt aircraft at-gate operations. The storage system will also allow aircraft to use the solar power directly at times when the solar facility is not producing power (e.g. at night or in rainy weather) rather than rely on an annual calculation of solar produced vs. gate power consumed to demonstrate the CO_2 offset. The gate equipment is also designed for mobility to allow aircraft at different gates to be served and maximize the number of aircraft and total amount of emissions to be reduced.

These projects provide a concrete example of how Member States can reduce international emissions through the deployment of renewable energy technologies that can be easily replicated by other States.

2.0 RENEWABLE ENERGY AND AIRPORTS

The renewable energy options available to airports are based on how airports use energy and which renewable energy technologies could serve as feasible alternative sources. This section first reviews airport energy use in the areas of electricity, heating, and transportation. Then it reviews the types of technologies available in electricity and heating that could serve as renewable replacements.

2.1 AIRPORT ENERGY USE

Airports require energy to transport people and goods efficiently. Large airports operate like cities that require major public infrastructure – highways, water pipes, power lines – to accommodate large numbers of travellers. Small airports may be a hub of activity served by local water and power, in an otherwise unpopulated or underdeveloped region.

Energy is a significant cost for airports. In the United States, energy makes up about 10 to 15 per cent of operating budgets at airports.[14] With the exception of personnel[15], it is the single largest airport operating expense. While the largest airports are the largest consumers of energy, they are also the most efficient users of energy on a per passenger basis.[16]

Figure 2-1 shows the different types of energy consumption activities at an airport. Heating fuel and electricity are delivered from off-site supplies. Heating is typically powered by oil or gas delivered by pipeline or truck. Electricity is delivered from the national grid, which is fed by a central power plant powered by coal, gas, oil, nuclear or renewable power, such as solar, wind or hydroelectric. The electricity supplies a variety of energy needs, from terminal lights to radar equipment, to computer systems. The aircraft when at the gate are either powered by jet fuel in the APU, with electricity from the terminal, or with GSE operating on the apron with diesel or gas.

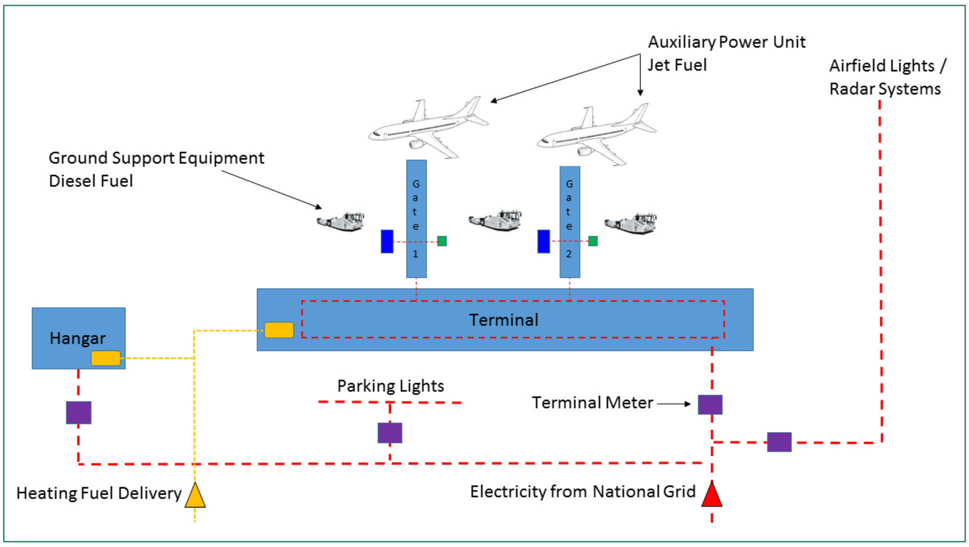

FIGURE 2-1
Airport energy sources (source: author)

2.1.1 AIRPORTS AND ELECTRICITY

Airports purchase electricity from the national grid, a vast network of electricity transmission lines and power flow control facilities. “The grid” is supplied by a variety of generators, as illustrated in **Figure 2-2**. Fossil fuel power plants which use coal, oil, and natural gas produce carbon-intensive electricity. Nuclear stations and renewable energy plants produce carbon free electricity, sometimes referred to as “green” power. All generating sources dispatch their electricity to the grid which is tapped by power consumers for everyday use. While there are polluting and clean forms of electricity generation, once the power is in the grid, users cannot distinguish between the different sources of energy. Individual users can physically develop their own electricity generating facilities on-site, such as solar panels placed on the roof of a house; but on-site power is a relatively new trend in areas otherwise served by the grid.

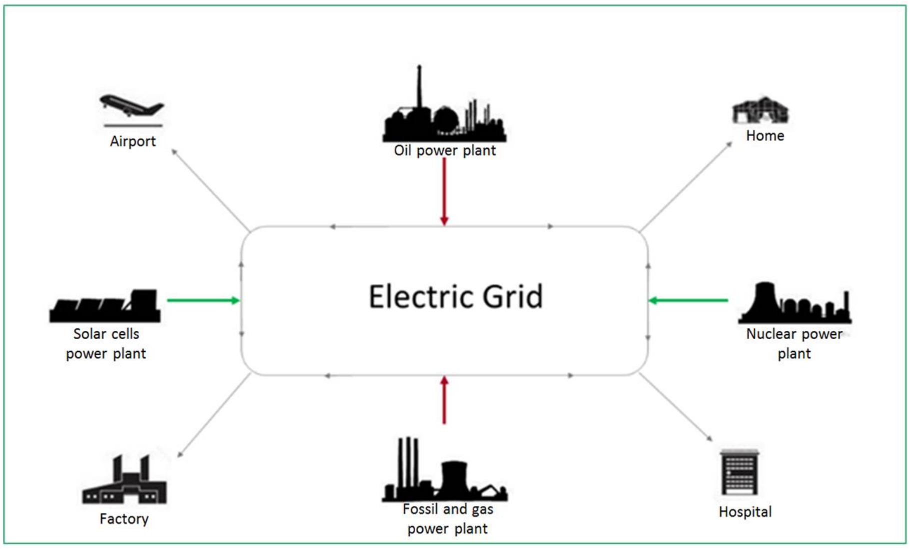

FIGURE 2-2
The electric grid stores and distributes electricity for societal use (source: author)

Airports require electricity for many of the same purposes that it serves in the broader society. Terminal buildings, large and small, require electricity for lighting, air conditioning and other building systems, and power to serve the needs of airport administration and the airport’s tenants to conduct typical business activities. This is particularly apparent for large terminal buildings with extensive lighting and heating/cooling challenges, as illustrated in **Figure 2-3**.

FIGURE 2-3
The airport terminal uses a considerable amount of electricity (source: Pixibay)

For example, in the United States, HVAC systems consume 40 per cent of all electricity at airports with most of that load necessary for air conditioning.[17] While lighting in commercial buildings typically accounts for 25 per cent of the buildings electrical demand,[18] this amount can increase to 40 per cent in airport terminal buildings.[19] Airports also have large electricity demands that are specific to their uses, including security, airfield lighting, navigational systems like radar, and baggage handling. As electricity is also an alternative to fossil fuel-burning transportation vehicles (see below), there are opportunities to increase electricity use and potentially decrease the environmental impacts of other airport activities through electrification.

2.1.2 AIRPORTS AND HEATING

Where electricity is generated off-site and delivered to users, heat is typically produced on-site within each building, or through a campus system, from fuel delivered to the site. Oil and diesel are delivered by large vehicles, while natural gas and propane may be delivered by large vehicles or by pipeline where such networks have been installed. Larger airports may have a central utility plant that generates heat and air-conditioning to all buildings in the airport campus. **Figure 2-4** shows a layout of a central utility plant at an airport.

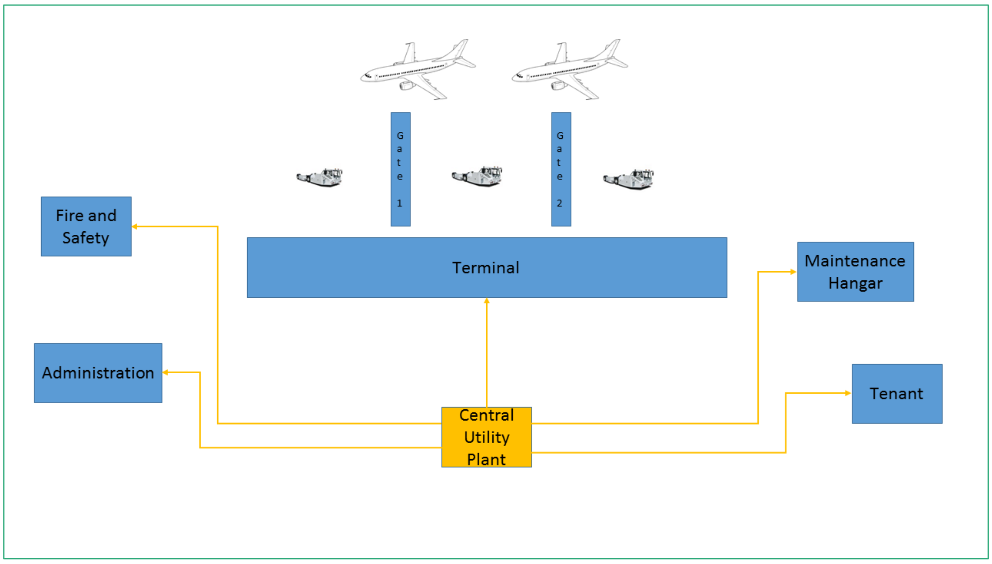

FIGURE 2-4
Central utility plant providing heating and cooling to airport buildings (source: author)

Electricity is necessary in all climates, but widespread space heating is only required in cooler climates. The heating and cooling needs of buildings are calculated based on a building code standard that often varies by country. For example, heating systems in Denmark are designed to begin operating when the outside temperature is 17° C or lower[20], whereas in the UK the base temperature is 15.5° C.[21] Heating demand should also include domestic hot water for most applications; however this is a relatively small use for airports.

Opportunities for renewable heat have been well described in other publications[22] and include biomass, solar, and geothermal sources. There have been some developments at airports in temperate zones which are highlighted in this guidance and the opportunities most favourable to airports are in electrification and associated renewable electricity sources.

2.1.3 AIRPORTS AND TRANSPORTATION

Airports also require energy for transportation and the most obvious sources is the jet fuel that powers aircraft which are fuelled at the airport. However, aircraft also require power when on the ground, as well as the support from an array of support vehicles that have traditionally operated on fossil fuels.

While the completion by Solar Impulse 2 of an around the world flight using solar power was an important achievement, the deployment of solar powered aircraft to replace the existing fleet remains only a longer-term prospect, particularly for long-haul trips. The current focus is on developing sustainable aviation fuels as a supplement and potential replacement for conventional aviation fuel for international civil aviation. ICAO is working with its Member States and partners to advance the development and implementation of sustainable aviation fuels.

Aircraft also utilize an APU, a small turbine generator that provides compressed air as well as electrical power for on-board equipment such as lights, avionics, galleys and instrumentation. The APU is typically located in the tail of the aircraft, as shown in **Figure 2-5** and is used when the aircraft is parked at the gate to regulate cabin temperature and provide power to on-board systems. Use of the APU and associated emissions can be reduced by modifying gates with electrification equipment that allow the aircraft to obtain power and air conditioning from the terminal. When gates are equipped with PCA units and 400 Hz GPU converters, the APU will operate only long enough to bring the aircraft to the gate and be connected to the terminal system.

FIGURE 2-5
Location of the APU
(source: Pixibay)

GSE is the mobile equipment that provides support to aircraft when they are on the ground. GSE includes GPU, fuel trucks, baggage carts, and catering trucks. GSEs transport cargo and packages at airports serving air delivery services. GSE are typically powered by gas and diesel fuel, though electric GSEs are becoming more available. Smaller GSE requiring less power are more cost-effective because they require smaller battery storage systems. Various types of GSE are shown in **Figure 2-6**.

FIGURE 2-6
Ground support equipment
(source: author)

Airports are also a hub for ground transportation delivering people and goods to the airport or within the airport boundary. While States can help airports by providing infrastructure to support various transportation modes, such as rail and subway stations, bus stops, and vehicle parking, such facilities are dependent on public demand beyond that which is required to support passenger vehicles. The use of public transportation is more energy efficient per passenger and some forms are being converted to cleaner burning natural gas and to electric power.

2.1.4 OPPORTUNITIES TO CONVERT AIRPORT POWER SOURCES TO RENEWABLES

There are four types of opportunities for converting airport power sources to renewables: on-site electricity, gate electrification, electric GSE, and on-site heating and cooling.

Given that the majority of electric grids are powered by fossil fuel fired power stations, it is likely that the electric power serving the gate is from a carbon-intensive source. An important step in understanding the carbon emission effects of the airport's electricity use is to determine the electricity generating sources used on the airport and the opportunities to convert these sources to on-site renewable technology.

ON-SITE RENEWABLE ELECTRICITY

Renewable electricity facilities, such as solar PV, have been installed successfully at airports around the world. However, designing projects that are compatible with aviation uses and effectively reducing carbon emissions is much more complex. Physically locating the renewable electricity facility on-site is one challenge, and matching its generation with the airport's existing consumption is a further challenge.

Because an airport's electricity is typically supplied by the electric grid, the development of on-site electricity fundamentally reduces the demand for off-site power. In some cases, though not likely at airports, the on-site generation may exceed on-site use allowing the surplus generation to spill back to the grid (also referred to as "net energy metering"). However, different airport electricity uses demand different quantities of power, and the airport can size projects to be co-located with each use (as measured by the electric meter) to supply electricity directly where it is needed and to replace that which was previously provided by the electrical grid. This strategy results in multiple smaller generation projects dispersed to each meter. There may also be opportunities to transition an existing fossil fuel combustion energy source currently on-site at the airport to electricity and generate the electricity with a renewable source, thus reducing carbon emissions from an on-site activity.

An alternative approach is to identify an appropriate location on airport property to site a larger project that matches the overall electricity demand of the airport. The site would need to be compatible with existing and future airport operations and be connected to existing electrical infrastructure to transmit the energy, and it should be noted that building new infrastructure could make the project unnecessarily cost-prohibitive. Electricity would flow back to the grid rather than directly to each airport source of demand, and meters would measure both the electricity generated by the renewable energy system and the power consumed at each meter, and reconcile the two to determine the amount of the airport's electricity that is "supplied" by a renewable source.

More information on the types of renewable electricity technologies are described in Section 2.2 of this guidance document.

ON-SITE RENEWABLE HEATING

Renewable heating can be employed as a direct replacement for existing heating facilities at the airport. The simplest way to accomplish this is to either retrofit an existing heating unit or install a replacement that burns renewable fuels such as biomass. A more complex alternative would be to install a different type of system for heating, such as a solar thermal or a geothermal, and distribute the heat using the building's existing distribution system, if possible.

It is typically easier to incorporate renewable heating technology into new construction projects or major renovations rather than a simple system replacement. This is because heating units are located inside the building and the heat distribution system may require a significant redesign to accommodate the renewable heating technology. Renewable electricity projects are more conducive to retrofits because they capture electricity external to the building and can use the existing building electricity network to distribute the power. Section 2.3 provides more information on specific renewable thermal technologies.

GATE ELECTRIFICATION

One step in eliminating emission sources from aircraft APUs and GPUs powered by fossil fuels is gate electrification, and this is accomplished by installing a PCA unit and a 400 Hz GPU to enable to aircraft to obtain power and cooling from the terminal. The PCA and GPU can either be attached to the passenger boarding bridge or installed on the apron as ground-mounted systems, depending on design requirements. A schematic showing the gate electrification units is shown in **Figure 2-7**. Gate power can consume a significant amount of electricity, and in one example from Los Angeles International Airport (LAX), which has converted all of its gates to electricity, gate electrification was estimated to be about 14 per cent of the terminal load.[23] Frequently, the gate units are equipped with electric submeters to track the electricity consumed in order to adequately charge the airline, as well as to measure emission reduction benefits.

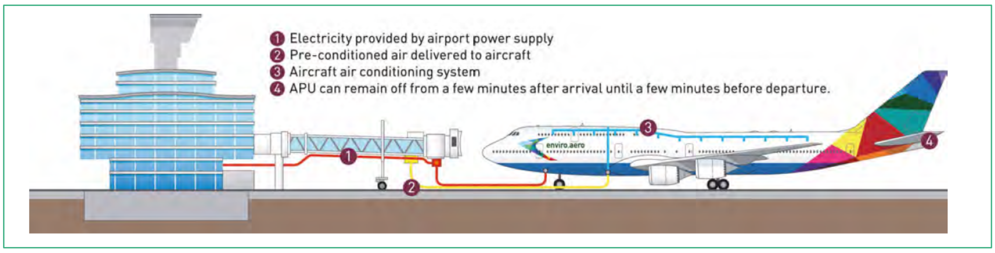

FIGURE 2-7
Gate electrification equipment (source: ATAG)

ELECTRIC GSE

When GSE is owned by the airport, cooperation is also required with airlines because such an investment has an impact on airport charges. Where GSE are owned by the airlines, the airport needs to develop a broader partnership to convert existing fossil fuelled vehicles to electric power. In such cases, the airline would agree to pay for the conversion of the GSE, while the airport would commit to installing electric charging stations on the apron where the GSE could charge. **Figure 2-8** shows a GSE charging station at an airport.

FIGURE 2-8
Airport GSE charging station (source: Pixibay)

ALTERNATIVE GROUND TRANSPORTATION

In addition to electrifying gates and GSE, there are opportunities to reduce emissions from other ground transportation arriving and departing the airport. Installing electric charging stations is an example of how an airport can support sustainable ground transportation. Airports can also transition their own parking shuttles and service trucks from traditional gasoline and diesel to cleaner burning natural gas and electric vehicles. Natural gas is often referred to as a bridge fuel because it is a cleaner burning fossil fuel which can lead to reduced carbon emissions, without immediately converting to renewables. Some airports that use diesel powered buses will achieve approximately a 27 per cent reduction in CO_2 emissions where buses are converted to compressed natural gas (CNG).[24]

In converting ground transportation to electricity, on-site emissions are reduced, but the airport, as discussed above, must understand the source of its off-site electricity to determine the extent of carbon emission reductions that is being achieved through electrification.

2.2 RENEWABLE ELECTRICITY

Renewable energy resources are naturally replenishing but flow-limited, meaning they are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave and tidal.[25]

The electricity generating technologies which are most capable of supplying electrical demand at an airport, due to the advancement in the technology, are solar PV, wind, hydro, and geothermal. Renewable thermal technologies are described in Section 2.3 of this guidance document.

2.2.1 SOLAR PV

TECHNOLOGY

Solar energy is necessary for life on earth. It powers the earth's climate, fuels the growth of plants as the foundation of the food chain, and provides heat and the environmental conditions where life can thrive. The modern use of solar energy for power takes both electricity and thermal forms.

Solar PV panels or modules convert light energy into electricity. The PV module is designed to maximize light capture which, through a series of chemical reactions, generates an electrical current. While a single solar panel generate usable electricity, expanding the area of light capture through the use of many solar panels increases the amount of electricity that can be generated. Multiple individual solar modules are connected in a line or a "string", as shown in **Figure 2-9**. The electricity generated by each module accumulates at the end of the string. Electricity from many strings is collected in a combiner box until the amount of electricity generated must be consumed or delivered. The solar facility produces electricity in direct current (DC) form. Most grids utilize alternating current (AC), which allows many users to draw off a single system. Therefore, the solar facility includes an inverter, which converts the electricity from DC to AC from where it is either consumed on-site or exported to the electric grid. Once in the grid, the solar electricity can no longer be distinguished from all other electricity generating sources.

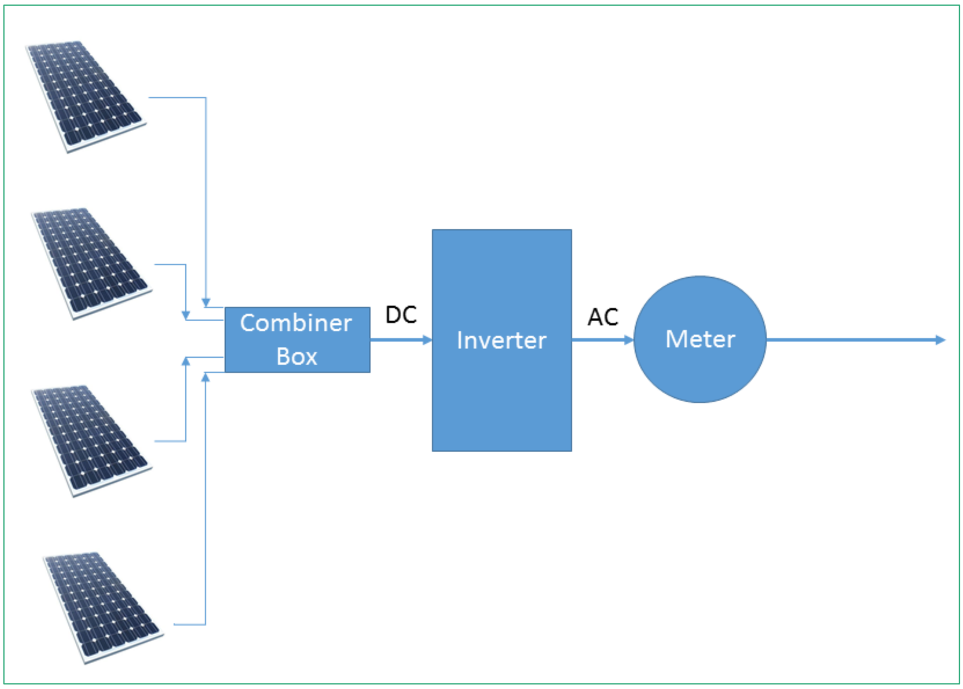

FIGURE 2-9
A string of solar PV modules (source: author)

There are several distinct advantages associated with using solar PV modules, and these are as follows:

1. A modular system makes it relatively easy to modify the size of a system simply by increasing or decreasing the number of solar modules. In this way, solar PV systems can readily be customized to any identified and preferred area.
2. It has a considerable amount of flexibility regarding where the system can be sited. This advantage is, in part, due to its modular make-up, but it also benefits from the flat design of the panels, which can be attached to or located in, a variety of locations. Panels can be attached to poles and placed in open and unused flatlands, or they can be attached to existing human-made structures that are oriented to receive sufficient natural light.
3. It can feasibly be deployed on any stable, terrestrial location in the world and generate electricity as all land receives some sunlight that can be converted into electricity. The amount of electricity generated and efficiency of the system varies among locations, with the sunniest areas producing the most electricity per panel. However, the optimization of power produced is primarily an issue of economics and not of physics, which also considers the cost of existing electricity being replaced and the cost of labour to develop.
4. The amount of electricity that will be produced by a solar facility for any particular location can be readily predicted based on existing knowledge of climate conditions. This is a significant advantage because the electricity produced will not vary significantly from year-to-year, which reduces financial risk when balancing capital invested and expected revenue or savings from future electricity production.

The main disadvantage of solar PV is that it only generates electricity during daylight, leaving it incapable of generating electricity for many consecutive hours at night. For an electrical grid that must maintain a stable supply of electricity, an alternative source must be activated to fill the deficit. Solar electricity can be stored in a battery for use during night-time, however, using batteries makes an already potentially expensive electric system more expensive. The alternative is to draw electricity from the grid at night and this becomes the customary choice. In addition, solar PV may not be a particularly efficient means of producing electricity when factoring night-time conditions, rainy and cloudy days, and variable levels of production during each day. If a solar panel were to produce electricity at its rated level all the time, it would be said that it produces 100 per cent of its potential. In reality, when factoring night-time, weather interruptions, and geographic location, solar panels typically only produce on average approximately 15 per cent of their potential. This means that other renewable energy technologies such as wind and hydro can be more efficient.

The amount of electricity that can be generated on a given surface area in a given time is referred to as solar insolation, and this varies by geography and climate. **Figure 2-10** shows the amount of electricity generated per day across the world, and this illustrates that areas closest to the equator have the greatest generation potential as shown by the darker colours.

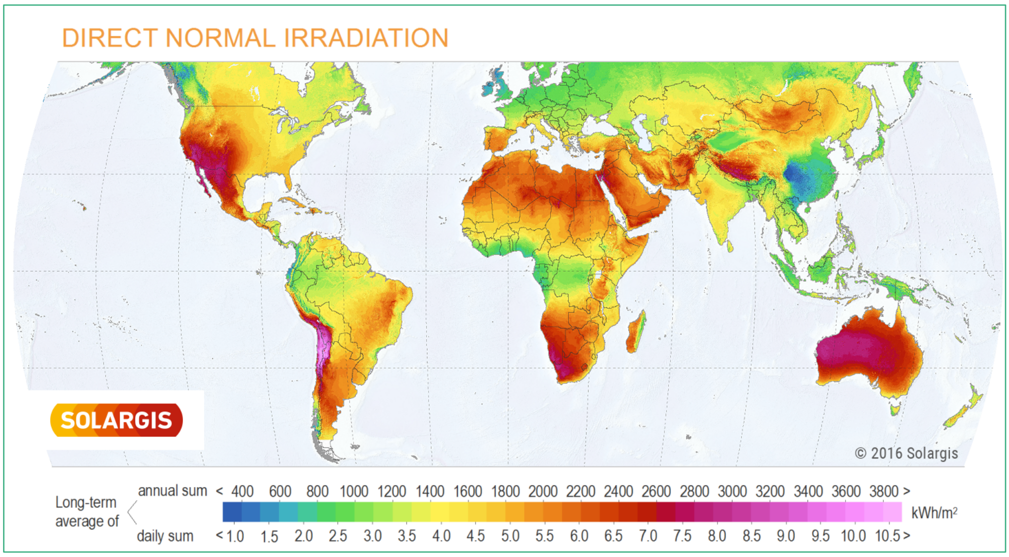

FIGURE 2-10
World solar insolation map (kWh/m2/day annual average) (source: DNI Solar Map © 2016 Solargis)

Solar electricity can also be produced by large concentrating solar power (CSP) plants. These facilities use mirrors to focus the energy for the sun on a tower to produce steam and drive a steam turbine. These projects have been developed in sunny and dry climates to supplement the electricity grid. Due to its large capital expense, CSP is only cost effective for national grid applications.

APPLICABILITY TO AIRPORTS

Solar PV is very compatible with airports due to its low profile and ability to integrate with existing development. Its low profile avoids causing a physical obstruction and a safety risk which can be a challenge for siting other renewable technologies, such as wind power, near airports. Solar can also be attached to existing or future buildings where the building structure (and not the solar project) is the controlling factor for airspace obstruction review. It can also be placed in many locations in the airfield, including in close proximity to runways without resulting in a physical impingement on airspace. One potential airspace issue with solar PV is glare and its potential to impact approaching aircraft and the air traffic control tower. Because solar panels have a smooth and shiny surface, they can generate glare particularly when the sun is low in the sky and can produce a glancing reflection. To ensure projects will not produce a glare impact, applicants must evaluate the potential of a visual impairment to air traffic controllers, pilots, and any other sensitive receptors on or near airport property as part of project siting. Projects should follow the appropriate State rules for assessing safety issues associated with solar PV projects, including ICAO Doc 9184, *Airport Planning Manual*, Part 1. An example of State regulations for evaluating potential safety issues related to solar PV projects is the US Federal Aviation Administration's Solar Glare Hazard Analysis Tool (SGHAT), available for use on the internet, can also be used to evaluate potential glare impacts.

Three different types of solar PV project designs from airport installations are provided in **Figure 2-11**, and include ground-mounted, roof-mounted, and canopy-supported. Ground-mounted are the least costly to develop and are typically used for large installations. Roof-mounted facilities are often the smallest and most expensive because they are attached to existing buildings, requiring detailed engineering. Canopy-supported facilities can be integrated into existing parking areas and provide covered parking for customers.

FIGURE 2-11
Examples of solar PV designs at airports (sources: Ohio –Travis DeVault, US Department of Agriculture Malta - Kurt Arrigo © Malta International Airport plc Aruba – Pfixx Solar)

All sorts of new solar PV innovations are in development and expected to be available in the near future. Thin-film is a product that would allow surfaces to be more easily covered in solar PV. Solar PV is being incorporated into other materials such as clothing to allow for collection of energy to power hand-held devices. In addition, solar ready building materials including roof shingles will allow builders to provide solar energy as part of new construction without modifying the building design with additional structures like solar panels.

Section 6 of this guidance document provides examples of renewable energy projects that have been constructed at airports. It includes roof-mounted projects located at George Airport in South Africa and Seymour Airport in the Galapagos, and a canopy supported project in Palau. The proposed 100 kW project proposed for Manley Airport in Kingston, Jamaica under the ICAO-UNDP assistance project will be a canopy-supported project located over existing parking areas. The proposed 500 kW project at Moi International Airport in Mombasa, Kenya and the 1 MW project at Douala International Airport in Douala, Cameroon are both proposed as ground-mounted designs.

2.2.2 WIND TECHNOLOGY

Wind power has been used for centuries to move boats, pump water, and grind grain. Prior to the widespread adoption of the combustion engine, sailing ships crossed the seas as the primary mover of international commerce and allowed for global exploration. The modern adaptation of wind power has simply inserted an electricity generator between the wind and the output to convert the power into electricity. As with solar PV discussed above, the generator produces DC but includes a built-in inverter to convert the power to AC for functional use.

For wind power to be economical, the wind must be comparatively strong and consistent.[26] The amount of energy produced by the wind rises exponentially with the wind speed, which means every increase in wind converted to energy results in a "cubed" increase (or an increase multiplied by itself three times). This condition has focused the wind energy industry on maximizing the amount of electricity that can be produced by any one single wind generating machine (traditionally referred to as a "windmill" but today called a wind turbine generator, or WTG).

Wind power projects have generally been situated in the windiest locations where they can feasibly be constructed. Such areas include flat plains, ridgetops, and coastal locations. More recently, large wind farms have also been constructed offshore of populated areas where the wind flows are unobstructed. A map showing offshore wind farms in operation (green) and in construction (blue) in Northern Europe is provided in **Figure 2-12**.

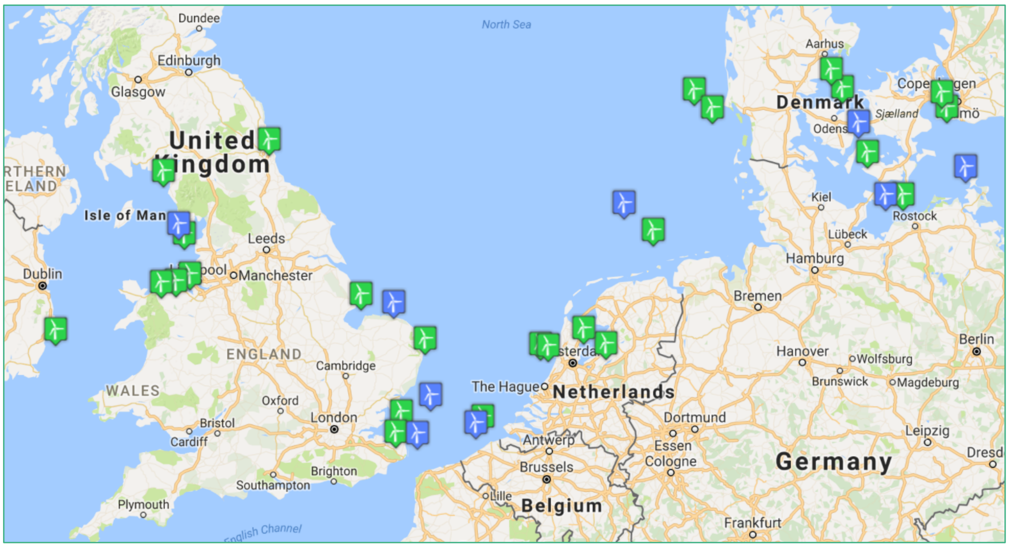

FIGURE 2-12
Offshore wind farms in operation and in construction in Northern Europe (source: 4coffshore)

In an effort to capture incrementally more wind energy, taller WTGs have been constructed and their windswept area (not unlike the area of a sail) has also grown. The typical size of a WTG, compared to other structures, is shown in in **Figure 2-13**. Typical offshore WTGs rise to 175 m above the sea at its highest point with blade lengths that are 75 m long. Taller turbines have increased the capacity factor for individual generators to be over 40 per cent of its maximum or rated output (typically known as the Nameplate capacity). For example, the capacity factor for one offshore Danish wind farm is measured to be 47 per cent over its operating life to date.[27] Solar PV, in comparison, produces about 15 per cent of its nameplate capacity. Wind power has become the second highest source of renewable energy worldwide as of 2014, behind only hydropower, as well as the second fastest growing technology worldwide, behind solar.[28]

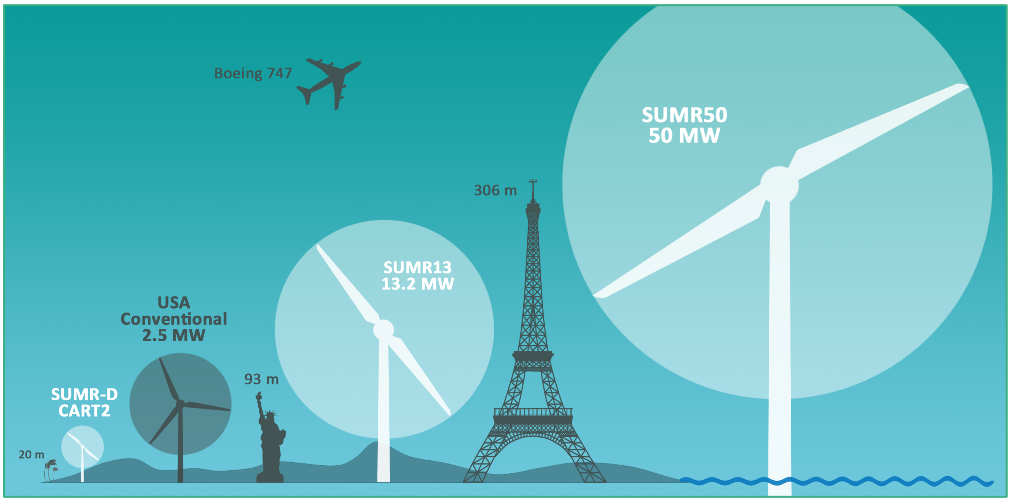

FIGURE 2-13
Size of a wind turbine generator compared to other structures (source: Segmented Morphing Ultralight Rotor (SUMR) Project, National Renewable Energy Laboratory)

The successful development of wind farms has resulted in a significant amount of renewable energy being fed directly into the national grid. Individual wind turbines can also provide cost effective electricity for on-site energy use if the site is located in a windy area, it has sufficient electricity demand, and the site can support a tall structure. Individual WTGs have been located at wastewater treatment plants, water treatment facilities, universities, and factories to provide on-site power where there is a large electricity demand. Projects must often consider the proximity to neighbours who can be affected by the construction of a large rotating structure.

APPLICABILITY TO AIRPORTS

Given the need to build tall structures to capture a sufficient amount of wind, WTGs are not conducive for use in airports as they will likely result in a physical impingement into the airspace associated with the airport. Despite the need for size, a few relatively tall wind turbines, rising from 35 to 50 m above ground have been located on airport property in compliance with airspace protection rules. While there may be some opportunity to site taller wind turbines at airports with large set-back between a WTG and the airport runways, the risk to aircraft tends to be greater than the potential benefits of implementing such a project.

As an alternative, several airports have constructed building-integrated wind turbines. The designs typically include placement of 10 to 20 small-scale wind turbines on the rooves of airport buildings. Typically, for large WTGs, the electricity-producing capacity of each wind turbine at maximum output is equivalent to four solar modules at maximum output. However, because the building-integrated design lacks the efficiency components of the large wind turbine, namely the large blade swept area (or sail) and the location 150 m above ground level, the blades on these wind turbines do not spin as often and efficiency is significantly diminished. These projects, because they are often visible, can be a symbol of interest and commitment from an airport in renewable energy. However, it must be noted that such projects will be unlikely to produce a quantity of renewable energy that achieves significant emissions reductions.

Section 6 of this guidance document includes a few examples of airports that have deployed wind power. East Midlands Airport in the United Kingdom has constructed two 45-metre tall wind turbines which could be options for other airports. Seymour Airport in the Galapagos has three slightly larger wind turbines which it may be able to accommodate safely due to the lack of terrain and development and available set-back from the airport. Building-integrated wind turbines have been constructed at a handful of airports in the U.S., including Boston, Minneapolis and Honolulu. Small, free-standing wind turbines of a small size have been deployed at Detroit Airport in the U.S. and Kansai International Airport in Japan.

2.2.3 HYDRO TECHNOLOGY

Electricity generated by flowing water, hydropower, is the largest source of renewable energy in the world. IRENA reported in its 2016 statistics that hydropower makes up nearly 74 per cent of the world's total renewable energy generation as of 2014.

People have used the power of rivers to transport people and goods and to pump water and mill grains for many centuries. Water power was critical to the industrial revolution beginning in Great Britain and in Europe and North America in the late 18th and early 19th Centuries. Shortly thereafter, modern hydroelectric power was demonstrated in late 1870s and within 30 years there were hydroelectric power stations from Niagara Falls to the Tanglangchuan River in China. Major hydroelectric power stations which provide substantial amounts of regional power have been built throughout the 20th Century up to the current time. As an example, Brazil has expanded its electricity production over the past decade by 40 per cent, of which 4/5 came from hydroelectric stations.[29]

While hydropower continues to provide a cost-effective way to bring a stable, renewable electricity supply to regions of the world that lack power, it is recognized that damming rivers can cause ecological damage.[30] To avoid these impacts, a smaller subset of hydropower technologies have been developed, which seeks to generate electricity from flowing water without dams. Turbine technologies placed in flowing rivers are referred to as run-of-the-river hydro. Other technologies are located in the ocean to capture energy from waves, tides, and ocean currents. These are all nascent technologies that are primarily in the testing phase.

Hydropower provides a huge advantage over most other renewable energy sources notably solar and wind. As water can be stored behind a dam and its flow and corresponding power output can be managed, hydropower represents the only "base load" renewable energy source. Once thought to also be carbon free, recent studies show that the reservoirs behind dam impoundments release methane, a carbon-carrying greenhouse gas.[31] Solar and wind electricity is only available when the sun is shining or the wind is blowing, unless a battery storage system is incorporated, which is expensive.

Moreover, because hydropower is producing a substantial amount of electricity over broad regions, those populations served only by hydropower are perhaps the first regions of the world to be living on carbon-free electricity. In fact, there are a number of countries that produce only renewable energy in the form of hydropower. This list is provided in **Table 2-1**.

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

*Ethiopia = 29 GWh Wind, 16 GWh Geothermal;
Iceland = 5,209 GWh Geothermal

APPLICABILITY TO AIRPORTS

While hydropower has a demonstrable record for generating large amounts of renewable energy, it requires a substantial investment to develop a project. Not only are the capital costs of land, concrete, electricity turbines, and modern control systems high, but development costs for permitting and studies are a significant risk. This is due in part to concern regarding the ecological impacts of hydroelectric projects. Hydropower is another technology that is logically developed at a large scale for grid applications and not for on-site use, though exceptions based on site location and available resources may occur.

2.2.4 GEOTHERMAL TECHNOLOGY

Geothermal technologies use the heat from the earth to provide power. Geothermal electricity facilities operate in a similar manner to traditional fossil fuel power stations in that the heat is used to make steam, which propels a steam turbine creating electricity (see **Figure 2-14**, US EPA 2017). As evidenced by Iceland's geothermal generation levels shown in Table 2-1, geothermal power can generate a significant amount of renewable energy where conditions permit.

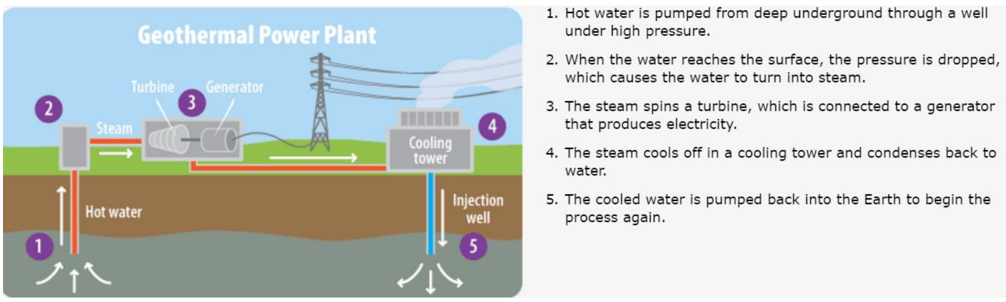

FIGURE 2-14
Geothermal electricity facility
(source: US EPA)

APPLICABILITY TO AIRPORTS

Like hydropower, geothermal electricity stations must be constructed at a large scale to produce electricity for the national grid to be economical. Geothermal is also very site specific with opportunities for feasible development concentrated in areas where heat from the earth's core is expressed near the earth's surface. For these reasons, geothermal electricity does not present an opportunity for on-airport development. However, a type of geothermal power referred to as "ground source heat pump", which utilizes renewable thermal energy, has been used at airports as described in the next section.

2.3 RENEWABLE THERMAL

Renewable thermal technologies are those which produce renewable power in the form of heat. As listed below, these technologies use many of the same natural resources presented above for electricity production, but use different resources and provide power in a different form. It is also important to note that the practicality of some natural resources for airport use may be better for thermal than is for electricity, and vice versa. Furthermore, there may be wide areas of the world where the need for renewable thermal is either not needed or is a low priority.

The renewable thermal technologies addressed below include geothermal heat pump, solar thermal and biomass. While thermal energy is an important component of the available renewable energy options, much of the guidance provided in this document subsequent to this section is more applicable to renewable electricity. However, airports should be mindful of the heating component of their carbon footprint where applicable.

2.3.1 GEOTHERMAL HEAT PUMP TECHNOLOGY

A geothermal heat pump is a heating and air conditioning system that utilizes the constant temperature of the earth to provide heating and cooling. Just a few meters below the earth's surface, the ground holds a constant temperature of about 7 to 8°C, while above ground the air temperature varies widely depending on climate and season. A geothermal heat pump utilizes the constant temperature below ground to pre-heat or pre-cool the temperature above ground, in order to limit additional heating and cooling energy needs as shown in **Figure 2-15** (US EPA, 2017). It requires seasonal temperature variations to achieve system balance, and therefore is only viable in temperate climates.

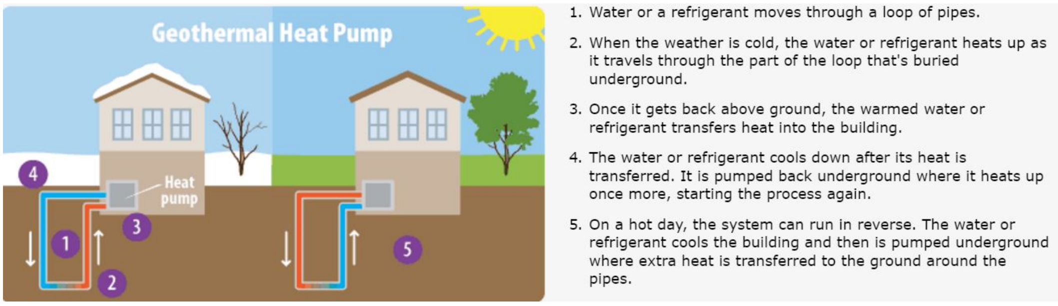

FIGURE 2-15
Geothermal heat pump (source: US EPA)

In warmer seasons, the system heats a solution at the surface and pumps it through a network of pipes into the ground. It replaces the underground solution stored at the 7 to 8°C temperature which is drawn to the surface to cool the building. In cold seasons, when surface temperatures are 0°C and below, the warmer solution below the ground is withdrawn to initiate heating of the building. As it will start at 7 to 8°C, it alone cannot provide the necessary heat and thus requires supplemental power to raise the temperature to a comfortable 18 to 21°C.

Given the existing underground temperature, the system tends to be more efficient at cooling as it does not require supplemental power to achieve the required indoor temperature level. Cooling will typically replace electricity generation and associated costs and carbon emissions. In winter, the underground temperature provides increased heating efficiency by pre-heating the solution and requiring less power to achieve the desired indoor temperature. Some sites may consider existing groundwater or surface water as part of the design, and achieve construction and operational benefits from the presence of a water resource.

Such systems also must be appropriately balanced to ensure that the long-term use of the ground does not result in a long-term underground warming or cooling which will degrade the effectiveness of the system. Geothermal heat pumps require development of deep wells penetrating into the earth 100-150 meters to maintain a constant subsurface temperature. They also require specialized building mechanical equipment to pump and move the solution. The heating and cooling can then be distributed through the building using conventional means such as air or water.

APPLICABILITY TO AIRPORTS

Geothermal heat pumps have been developed as part of new and rehabilitated terminal building projects in North America and Europe. These projects have demonstrated success in providing renewable thermal energy for large heating and cooling loads. As the efficiency of the systems depends on ambient temperatures that have considerable variability, it is not uncommon for projects to experience a long commissioning phase to achieve balancing appropriate to the facility, and optimize operations. Geothermal heat pumps are most cost-effective when incorporated into a new development or major renovations as they may require new heating and cooling distribution systems internal to the building. However, projects have been integrated into existing airport buildings, including one at a small airport in Pennsylvania in the United States.[32] A project example at Stockholm-Arlanda International Airport is described in Section 6 of this guidance document. Similar projects have been constructed at Paris-Orly Airport, France; Nashville Airport, United States; and Calgary Airport, Canada.

2.3.2 SOLAR THERMAL TECHNOLOGY

The properties associated with solar thermal can be experienced anytime you stand in the sun and feel its warmth. That heat energy can be focused with mirrors to create steam and generate electricity in a concentrating solar power (CSP) plant as described above, or it can be used to provide heat on-site to a building.

For on-site use, solar thermal panels are typically placed on top of buildings where they will be unshaded and can return heat to the building they serve. Tubes filled with water or a similar solution pass through the panel and as it is heated, the solution moves into the building to provide heat for typical domestic purposes including heating the building and hot water. As with solar PV, solar thermal is modular, making it relatively easy to design and expand based on project objectives and available space. Solar thermal has been particularly successful for residential uses given the varied needs for hot water.

A variation of the solar thermal panel which heats a solution is a solar wall which heats air. With the solar wall technology, the sun heats a large building facade and the air behind the wall also heats. That air is then distributed through the facility using a traditional forced hot air system.

APPLICABILITY TO AIRPORTS

Solar thermal panels have been deployed at a number of airports. As with solar PV, solar thermal panels can be placed on the roof of an airport building and provide thermal energy to that building. This design consideration demonstrates the technical feasibility of developing such systems. As solar thermal is particularly effective for domestic hot water use, it has been deployed more successfully for a residential capacity and for commercial uses which require hot water. Because airports typically do not have high hot water requirements, the usefulness of solar thermal has not been well documented. In addition, solar thermal is more expensive then solar PV, and therefore airports have chosen to deploy more solar PV. Solar thermal facilities at airports should also be reviewed for potential glare impacts. Projects have been constructed at airports in Geneva, Toronto, and a small airport in Minnesota.

2.3.3 BIOMASS TECHNOLOGY

Biomass is non-fossil material of biological origin constituting a renewable energy source. It is used as a fuel to generate electricity or heat. As an electricity generator, it can be designed as a regional power station to generate electricity via a steam turbine, like geothermal and solar thermal electricity. As a heating unit, it provides an alternative to conventional fuels used in building energy systems.

Biomass, in the form of wood, has been used and continues to be used throughout the world as fuel for cooking and heating. In warm climates, wood may be the cheapest and most accessible fuel to meet cooking needs. In temperate zones, wood is used for heating across all social and economic strata. Dried animal waste is another form of biomass used in parts of the world. A key component of the biomass is the source of the crop and if it is being managed in a sustainable manner. The challenge with using biomass is managing the wood resource to ensure that it is not excessively depleted.

Biomass has been most readily developed in areas where there is a large forest resource that can provide an inexpensive source of fuel. This fuel is primarily generated as a waste from the production of wood products. Waste wood is formulated into wood pellets that can be burned in a stove for household use or a boiler for larger buildings. It is also feasible to grow other crops for fuel, including those used to manufacture sustainable aviation fuel. The best fuel options are those that grow quickly so that the life cycle of plant growth can keep up with the demand for fuel. Related technologies include waste-to-energy, where domestic wastes are used as fuel, and anaerobic digestion, where organic wastes are processed to create methane to be used as a fuel. These technologies have been primarily deployed as regional sources of electricity rather than for heating.

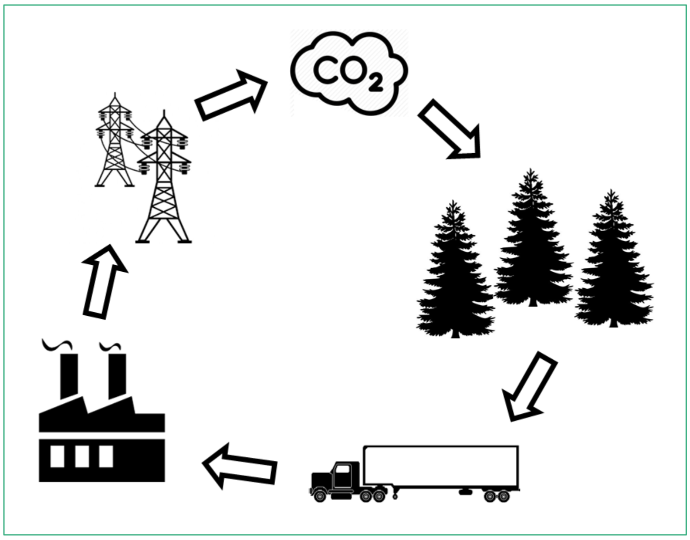

FIGURE 2-16
Biomass carbon cycle
(for the example of wood waste)
(source: author)

Biomass energy, whether generated for the purposes of electricity or heating, does produce emissions, including CO_2. By using biomass, low life cycle CO_2 emissions can be achieved. This allows for plants to absorb CO_2 for growth during photosynthesis in relatively short time scales. This carbon is emitted back into the atmosphere during combustion and will return to the plants in a closed loop. Therefore, ideally, no additional carbon would be injected into the biosphere as it would be the case for fossil fuels. The full carbon cycle from carbon capture in wood to carbon release through combustion is illustrated in **Figure 2-16**.

An advantage of biomass is that it works in a similar way to conventional heating fuels so it can be technologically simple to convert or replace existing boilers with those that burn biomass. A disadvantage of biomass is that the fuel must be regularly transported to and stored on-site. Large trucks must be deployed to bring the biomass fuel on a continuous basis to the facility site and a large storage area must be established to keep the fuel on-site in between shipments. In addition, because there are emissions produced, there can also be local air quality impacts and regulatory frameworks that do not allow for their use.

APPLICABILITY TO AIRPORTS

Biomass has been used by airports in a few cases to provide heat for building needs. These projects have primarily been accomplished by replacing an existing fossil fuel boiler with one powered by biomass. These projects have often been located in areas where there is an existing forestry resource and availability of processed biomass-related wood fuel. Identifying space for biofuel storage and timing of biofuel delivery have been important factors for some of the projects located at larger airports. The cost-effectiveness depends on the cost of the biomass fuel compared to the cost of other available power.

A project example using biomass is included in Section 6. It is an example of a boiler replacement for a small airport in the Northwest Territories in Canada. Other examples include projects at Landvetter in Gothenberg Sweden, Heathrow and Stanstead in the United Kingdom, and Alaska and Oregon in the United States.

2.4 MICROGRIDS

An electric grid is a power system consisting of generation, distribution, and consumption. Typically, electric grids serve wide and interconnected areas with power generated by a few large stations, distribution controlled by equipment and system operators, and consumption from many diverse electricity users drawing power from the network as needed. A key component of the electric grid is stability, which includes matching power generation with changing power demands over time and maintaining a constant and level supply of electricity. These same principles apply to microgrids, with the major difference being that microgrids serve a much smaller area. While not all microgrids are connected to the national grid (e.g. islands), it is assumed that the airport microgrid has an existing connection to the national grid. The purpose of establishing a microgrid that is connected to the national grid is to provide locally-controlled power autonomously from the electric grid and realize associated benefits.[33] **Figure 2-17** provides an illustration of how the microgrid is used in combination with the electric grid.

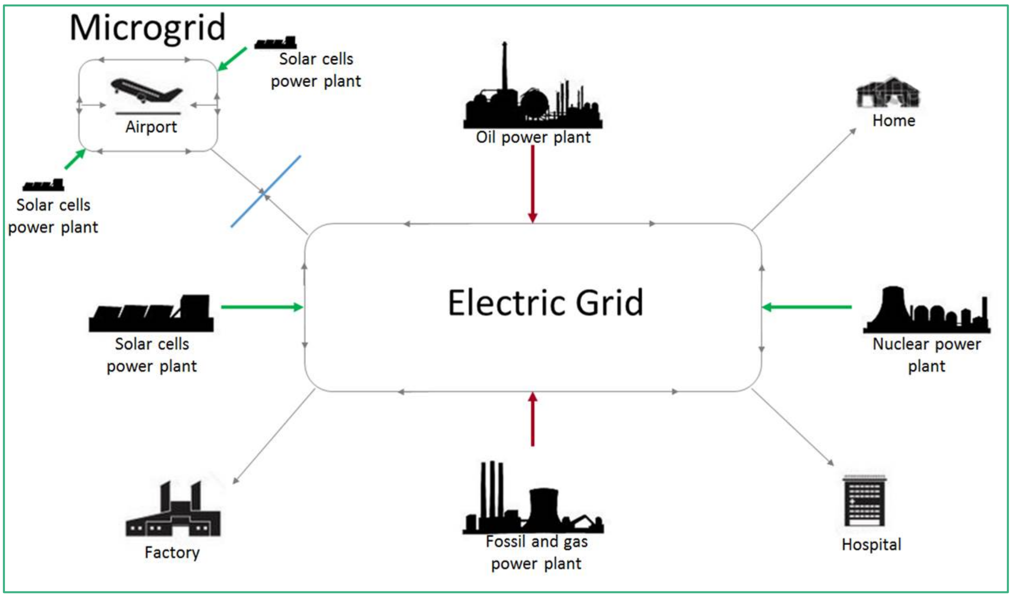

FIGURE 2-17
Microgrid in connection with the electrical grid (source: author)

The development of a microgrid requires an investment in equipment and knowledge that is currently under the purview of the national grid operator. Since the objective of airports is aviation and not energy, it may be challenging for them to acquire the expertise to design and operate a microgrid. Yet, microgrids can provide substantial benefits to airports, and to society at-large, by enabling air travel to occur even during a failure of regional electrical services. Microgrids can also isolate airports from the consequences of periodic power loss in areas that suffer from electric grid power instability. The three main components that airports should consider when assessing a microgrid are infrastructure, supplemental generation and storage.

2.4.1 INFRASTRUCTURE

Under current conditions, airports are one of many consumers of electricity from the broader electricity grid. Like other users of the grid, the airport can develop on-site electrical power generation as a supplement to their power needs, but the grid in most locations will remain the most reliable source of power. In developing a microgrid, the owner is seeking to shift the level of power certainty from the grid to the microgrid, thereby improving upon the reliability of local electricity supply.

Even in a future case of a microgrid, the on-site electrical system will remain connected to the national grid which will provide a backup and supplemental source of power, and serve as energy storage for excess power generated on-site. Given this connection, all components of the microgrid must be compatible with and designed to the electrical codes and standards of the national grid. The primary infrastructure upgrades required for the microgrid include a gate, referred to as a Point of Common Coupling (PCC), at the connection between the microgrid and the national grid, and distribution enhancements that will allow for a self-contained transmission network within the microgrid.

The PCC allows the microgrid to sever the connection between the national grid and microgrid, a condition which is often referred to as "islanding." The PCC is designed such that, under normal operating conditions, the gate is open and power between the microgrid and national grid is monitored and flows freely. The airport will import or export power depending on technical or commercial conditions. It also contains safety features to protect each grid system from a fault or failure caused by the other, as well as "disconnects" that shut down the flow of power from generation sources allowing electrical workers to perform maintenance. Given the small size of the microgrid network and to increase flexibility in generating and distributing power throughout the campus, distribution lines must be upgraded to promote a consistent level of power.

As part of the infrastructure upgrade, a sophisticated monitoring and control system, frequently referred to as the Energy Management System (EMS), must be incorporated to allow local managers to effectively control power generation sources to match facility generation periods and local demand. For example, if solar is one of the generation sources, its load must be monitored to allow for balancing with base load sources and control of stored energy to respond to solar generation changes during the course of the day and provide replacement load at night.

2.4.2 SUPPLEMENTAL GENERATION

For the microgrid to operate and provide reliable power autonomously, it must include power generation sources that will ensure a certain and consistent supply of power. The microgrid may contain a single power source or multiple power sources, but typically multiple sources are necessary to provide redundancy and flexibility to accommodate various operating conditions.

Renewable electricity sources, like solar and wind, may offer an advantage when coupled to a microgrid in that they can generate power on-site without requiring delivery of an off-site fuel source, as required by fossil fuels and bioenergy. However, renewable sources are intermittent, meaning that they only generate electricity at certain times (e.g., the sun is shining or the wind is blowing). To address this issue, battery storage can be used to store energy for use when the intermittent renewable power is not being generated. Alternatively, the renewable energy can be paired with a base load generator, such as a fossil fuel or bioenergy fired facility to provide redundancy and support to address a variety of potential conditions.

A fuel cell is considered to be a reliable hybrid option. Fuel cells generate electricity through a chemical reaction which is catalyzed by an outside fuel source. Once the chemical reaction commences, an electricity flow is created, releasing heat and emissions as by-products, depending on the initial fuel source. Most contemporary fuel cells have a source of natural gas that catalyzes the chemical reaction which will result in some limited amount of emissions. However, because the fuel use is limited to sustaining the reaction but not producing the electricity, emission levels are relatively low. Future fuel cells could be powered by hydrogen, which once cycled through the fuel cell catalytic process, would have as a by-product water and heat.[34]

Generation options will be determined by the resources available to the airport based on climate and geography.

2.4.3 STORAGE OF ENERGY

A key component of any renewable energy strategy, which is heightened even further in the context of the microgrid, is energy storage. Storage technologies allow managers to maximize high electricity production periods and store excess electricity for use in the future when electricity generating options are limited.

There are a variety of storage options,[35] and as discussed above in section 2.2.3, impounding water behind a dam is a form of energy storage in that the water is held and ready to be released for electricity production when needed. This is an example where the resource can be controlled and deployed when needed. With many other renewable energy resources, the timing of the resource to produce electricity cannot be controlled.

The most effective and well-known storage option is the battery, which has been used to power small devices and large equipment for many years. Today, research is being conducted to improve operational life and capacity, and reduce component size and development costs. Many of the batteries used for power storage are based on the same principles as the original batteries though the use of batteries has expanded greatly from small devices to cars and planes. Large batteries have been deployed in national grid networks as pilots to improve reliability and distribution.

Other innovative technologies are being tested and deployed for local and grid-level use. One is a flywheel, a large spring system whereby power is deployed to coil up a large spring which can be later released and used as energy. Another is to use generated power to compress and trap air that can be released and used at a later time. Both of these are shown in **Figure 2-18**.

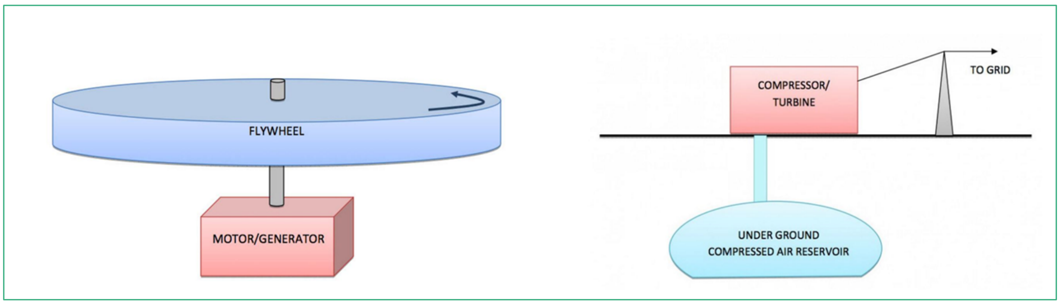

FIGURE 2-18
Energy storage alternatives to the battery (source: author)

A 20 MW flywheel storage system is in operation in Pennsylvania in the United States as shown in **Figure 2-19**. This system is made of multiple flywheels each of which stores energy for release at a later time.

FIGURE 2-19
A facility in Pennsylvania comprised of multiple flywheels to store electricity (source: Beacon Power)

The U.S. Department of Energy manages a website containing the global energy storage database.[36] It includes an entry that the Benito Juarez International Airport in Mexico City purchased three flywheels in 2014 to provide 390 kW of energy storage.

At San Antonio International Airport in Texas, a storage tank holds thermal energy for later use.

Storage technology, in addition to a baseload source, is important to the implementation of any microgrid system. The microgrid, in order to function properly, must be controlled with sophisticated system to balance electricity generation and usage. Storage is the ultimate control device for electricity as it is energy waiting to be deployed.

2.4.4 SYSTEM BALANCING

To function effectively, the microgrid must be balanced. This is accomplished at the EMS, the nerve centre for the microgrid. The EMS must balance energy generation with demand and use energy storage to keep the system stable as illustrated in **Figure 2-20**.

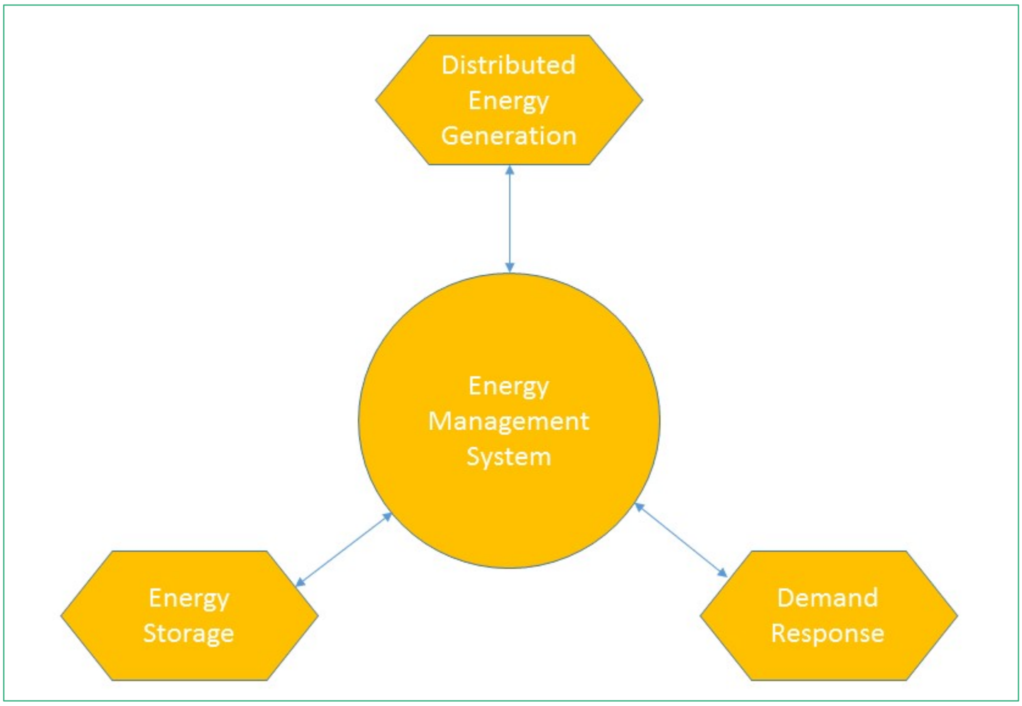

FIGURE 2-20 Microgrid system balancing (source: author)

3.0 PROJECT CONCEPTUALIZATION

When beginning to consider a renewable energy option, airports should follow a series of evaluations to help them conceptualize and define the project. First, they need to clearly articulate why they want to pursue the project. Second, they need to conduct a review of the regulatory programmes that influence energy project development in the area. Third, they need to evaluate how such a project would be defined by their specific operational conditions given their size, climate and other factors. Finally, using the information gathered in the previous steps, they would evaluate the technical feasibility of a project at their airport using a series of criteria. Each step provides further focus for the project, as illustrated in Figure 3-1. Each step is described in detail below and working through this process, the airport can identify a specific renewable energy project and location.

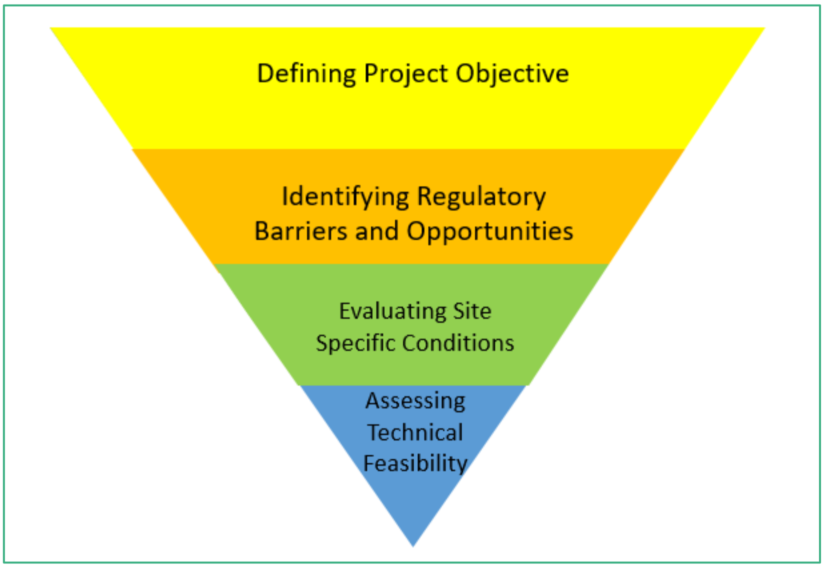

FIGURE 3-1
Initial steps in project conceptualization (source: author)

3.1 DEFINING PROJECT OBJECTIVES

There are a variety of reasons why an airport may wish to pursue a renewable energy project. It may have a singular objective or identified multiple objectives. As an important first step, the airport should define the project objectives to make sure there is a clear understanding of why the project is important to the airport's core mission. Then it will need to communicate its objectives regularly during project development to ensure that its intent in pursuing the project is well grounded. Some potential objectives for pursuing a renewable energy project at an airport are described as follows.

3.1.1 EMISSIONS REDUCTION

A core characteristic of renewable energy is that it produces (in most cases) zero emissions and provides the opportunity to make progress toward carbon emission reduction goals. ICAO Member States and airports may have identified climate mitigation goals and targets, as well as a plan to reach those targets. An example is the State Action Plan on CO_2 emissions reduction activities for international civil aviation that many ICAO Member States have already prepared.[37] A renewable energy project may be identified by a State as a measurable action that can be undertaken consistent with its State Action Plan.

3.1.2 ECONOMIC DEVELOPMENT

As discussed above, international aviation is a vehicle for economic and social development around the globe. As countries develop and gain economic prosperity, their energy consumption also grows. Implementing renewable energy projects achieves both economic development, and reduces the risks of climate change. It is recognized that the future of economic development will need to be conducted using more sustainability principles, and that renewable energy will likely be a central facet of that growth. Furthermore, energy is a global business and renewable energy is an expanding sector. Airports can be catalysts for demonstrating new technology in a State and attracting new energy businesses and energy-related development. Deploying renewable energy at the airport is one way to make this clear to travellers.

3.1.3 IMPROVING POWER STABILITY

An airport may be located in an area where the power provided by the national grid is unreliable. Periodic loss of power, even for a matter of seconds, can compromise existing systems and deter economic development. The airport may seek ways to generate electricity or thermal power on-site where it can be more reasonably controlled for the airport's needs. Deploying renewable energy, potentially along with a storage system, could enhance power reliability for the airport, improve the efficiency of its operations and enhance its services to its customers. If developed as part of a long-term microgrid strategy, the project could also isolate the airport from major disruptions of grid failure caused by a natural disaster or human intervention.

3.1.4 INCREASING LEADERSHIP POSITION

Airports are a focal point for a region's economic development. Travellers pass through the airport, whether it is for business or pleasure, and the airport is a symbol for the region. The State and the airport have an opportunity to take a leadership position in demonstrating new technologies. Renewable energy use that is visible at the airport will make a striking impression to travellers demonstrating the airport's and region's economic and technological progress. It will also demonstrate to local authorities and the population the commitment to reducing the impact of aviation on the environment.

3.2 IDENTIFYING REGULATORY BARRIERS AND OPPORTUNITIES

There are a number of procedural mechanisms that have been utilized by proponents of renewable energy to assist in the development of their projects. These programmes are discussed in detail in a complementary guidance document on regulatory and organizational changes. The following section reviews some of these energy programmes and how they may be implemented.

3.2.1 NET ENERGY METERING

Net energy metering is the process whereby a customer of the national grid develops an on-site electricity generating source to allow it to consume some of its own electricity on-site, export surplus energy back to the grid at times of overproduction, and still purchase electricity from the grid when necessary. This concept is illustrated in **Figure 3-2**. As the customer will be potentially transmitting power back to the grid, it must work closely with the grid operator during design and construction to ensure that the generating system is compatible with the grid, will not disrupt the flow of electricity on the grid, and can be accessed by grid operators should maintenance be required on lines downstream of the generation facility. In addition to these technological issues, local jurisdictions must establish net metering rules to regulate and manage the net metering activities.

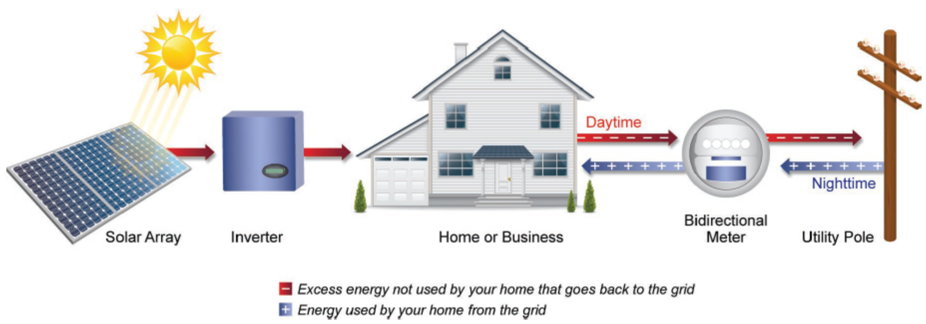

FIGURE 3-2
The concept of net energy metering (source: HMMH)

One of the most important issues associated with net metering rules is whether the customer will receive any compensation for the surplus energy it exports back to the grid, and, if so, what the value based on. The customer would like to receive as much compensation as possible, as those payments will accelerate or reduce the time period when the customer makes back the money invested in the generation system. The national grid operator wants to minimize any payments as it is already losing revenue that it had previously earned when it sold the customer electricity and now must pay the customer for their excess energy as well. Additional rules that cap the total amount of energy that can be exported, either on a site-by-site basis, or as an aggregate over the grid operator's service territory, may also be imposed as part of a local programme. Net energy metering policies that provide larger compensations for the on-site generator, even up to the rate it buys electricity from the grid operator (referred to as the retail rate), are supportive of renewable energy projects.

Airports can benefit from net metering because it allows them to export electricity back to the national grid when it is not needed for use on-site and receive compensation. Airports working with their State (e.g. with the civil aviation authority) should ask their national utility about net metering and compensation for surplus energy.

3.2.2 FEED-IN TARIFFS

Feed-in Tariffs (or FITs) are electricity acquisition policies that establish a price to be paid by the grid operator for new power generation based on the actual cost to develop the technology. Typically, there will be a different price per kilowatt hour of electricity delivered by the project for different technology types. For example, it is generally more expensive to generate a kilowatt of solar electricity compared to a kilowatt of wind, so higher prices will be paid for solar power. The advantage of the FIT is that the renewable energy project developer will obtain a signed contract in advance from the grid operator identifying the price that will be paid for the power, which the developer can use to secure financing for the project. The downside of FITs is that the grid operator must put a limit on the total capacity that can be procured, which can result in boom and bust development cycles.

Airports will benefit from FITs because it will guarantee that the energy produced by the airport will be paid for, and that the airport will receive payment. Furthermore, under the FIT, the airport will know exactly how much it will be paid for the power, and this means it can better understand and predict the financial benefit of the renewable energy investment. Airports working with their State (e.g. with the civil aviation authority) should communicate with the State energy ministry and energy stakeholders about the potential of FIT legislation in their country.

Some examples of the use of FIT include the Weeze Airport in Germany, which installed 4 MW of solar on carport canopies funded through a FIT authorized by the German Renewable Energy Sources Act. [38] The 25 MW solar project at Indianapolis Airport in Indiana was also funded through a FIT issued by the local utility, the Indianapolis Power & Light.[39] A 19-MW project at Kuala Lumpur Airport in Malaysia was also funded through a FIT.[40]

3.2.3 TAX INCENTIVES

Tax incentives are an alternative to the FIT. The intent of the tax incentive is to provide private investors with an opportunity to limit tax liability by investing in a renewable energy project. The end result is that project developers can monetize a tax benefit and produce the renewable electricity at a lower rate with that subsidy. Where the FIT sets the price and guarantees a level of profit, the tax incentive gives all developers the same tax incentive and allows them to find a customer willing to pay the power price for the electricity. Those customers could be the grid operator, public customers like government or public universities, or private companies who wish to own renewable energy. Tax incentives may be packaged with other programmes which require grid operators to purchase renewable energy to drive the market demand for purchasing renewable energy.

As airports are sometimes public organizations that do not have a tax liability, they may not be able to directly benefit from a tax incentive. In these cases, they can partner with a tax paying entity to develop a project on airport land and the private entity can pass along a portion of the incentive value to the airport as payment for its participation.

Tax incentives have been used extensively in the United States, and solar projects at Boston, Denver, and San Diego all were constructed and are owned by private developers who can monetize the tax incentive and pass the savings on to the airport in lower electricity prices.[41] The availability of tax incentives varies among jurisdictions and airports should discuss potential tax advantages with the appropriate ministry in their State.

3.2.4 POWER PURCHASE AGREEMENTS

Power purchase agreements (PPA) are contracts for buying power over long periods of time. Renewable energy developers seek buyers of their electricity to support project financing, similar to that described above for the FIT. When a deal is consummated, the parties will execute a PPA which establishes the annual price and term for the electricity purchase as well as other terms and conditions. Power purchasers could be the grid operator, or any public or private organization.

A common airport renewable energy arrangement is where a private developer builds, owns, and operates a facility on land it leases from the airport, and then sells the electricity back to the airport through a PPA. Under such arrangements, the airport may have options during the life of the contract to purchase the facility from the private developer for a set price. Much of the developer's profit is accrued in the first 5 to 7 years of the project when the tax incentives are monetized. In addition, over time, the airport may acquire sufficient knowledge to allow it to better own and operate the facility, making a future purchase mutually beneficial.

PPAs have been executed between energy developers and airports including in Belfast, United Kingdom, [42] Karratha Airport, Australia, [43] and Chandigarh Airport, India.[44]

3.3 ASSESSING PROJECT FEASIBILITY

Equipped with knowledge of the energy regulatory programmes that may affect how a project is developed, the next step is to focus on the project site attributes to determine what type of renewable energy project is suitable. To accomplish this, existing conditions including geography and access to renewable energy, facility size and uses, and energy use must be considered. This information can then be used to specify a future condition with renewable energy including project site and technology to determine project feasibility.

3.3.1 EXISTING CONDITIONS

Airports exist in a variety of forms and provide different services under the common thread of providing air transport service. Large airports serve as international travel hubs, while small airports are key outposts for remote communities. There is no particular size or use of an airport that is better or worse for renewable energy. However, the size and use will affect the type of location of a project. All airports have the potential to develop on-site renewable energy; however, how they develop their projects may differ based on size and uses. For instance, large airports are likely served by large electric utility infrastructure which could potentially accommodate a large renewable energy generation project, whereas a small airport in a remote location may not be served by a large electric utility infrastructure, and will likely consider a smaller project more closely matched with their needs. However, a small airport with a reasonable amount of underutilized property may be able to consider a large project if it is in close proximity to a large electric transmission line.

Existing electricity is likely supplied by the national electricity grid. The power is generated from a regional power plant and the airport is one of the grid operator's customers purchasing electricity from the grid. How that electricity is generated from the regional grid will vary from location to location depending on the fuel sources available. As of 2013, 67 per cent of the world's electricity was produced from fossil fuel sources.[45] In its 2016 Medium-Term Report on Renewable Energy, the IEA stated that renewable power accounted for more than half of the world's additional electricity capacity in 2015 as the result of supportive government policies and sharp cost reductions.[46] The cost of power varies widely depending on supply and geography. One study of electricity costs (when converted to U.S. dollars) showed that emerging nations such as India, China and Mexico pay the least for electricity, while European countries (Denmark, Germany, Spain) pay the most as shown in **Figure 3-3**.[47]

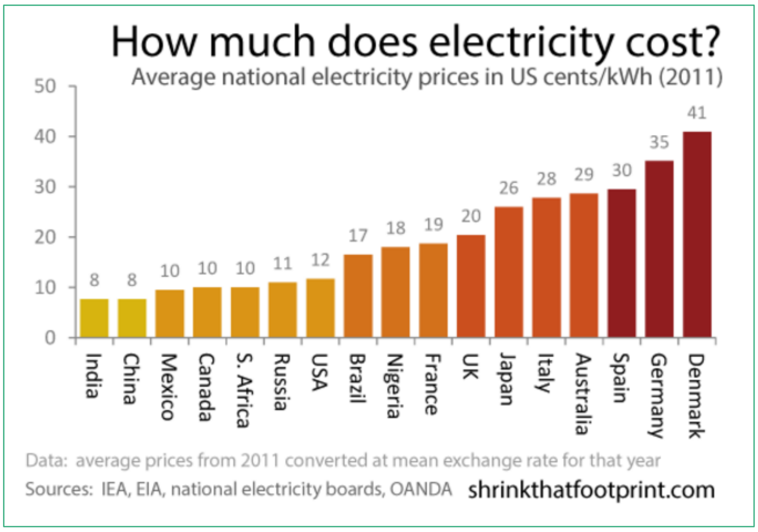

FIGURE 3-3
Electricity prices in 17 States (2011) (source: IEA, EIA, national electricity boards, OANDA)

Another study commissioned by the Philippine utility Meralco surveyed 44 States and showed that the highest electricity prices are paid by islands and island States as shown in **Figure 3-4**.

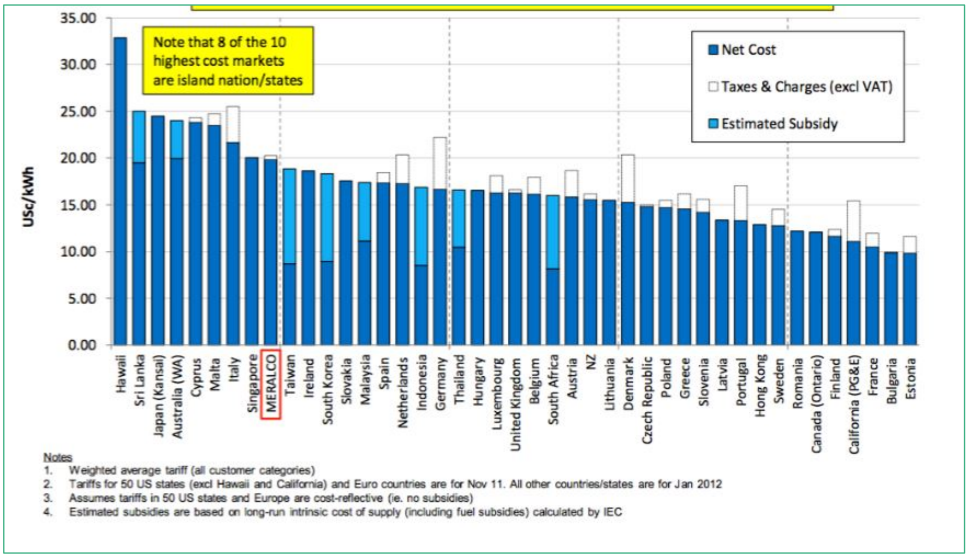

FIGURE 3-4
Electricity prices surveyed for 44 States by the Philippine Utility Meralco (2012) (source: MERALCO)

Where electricity prices are high, the payback for an investment in renewable energy can be achieved more quickly. It is after the payback is reached, when renewable energy provides is greatest economic benefit as costs are limited to operations and maintenance to keep the facility functional. Renewable energy located in States with the highest electricity prices, like solar at Honolulu Airport in Hawaii[48] and Karratha Airport in Australia[49], and solar[50] and wind at Kansai Airport in Japan are most cost-effective.[51]

Geography and climate are central to determining potential for generating on-site renewable energy. For example, project sites located in latitudes close to the equator typically have the greater amounts of sunshine and should focus on opportunities associated with solar power. Airports located in higher latitudes can maximize the potential benefits of geothermal heat pumps, which benefit from the wide variation in winter and summer extreme temperatures. Wind, hydropower, and biomass are dependent on the project site's proximity to associated renewable resources. For wind, the best locations will be high elevation lands and those close to the ocean or potentially other large bodies of water and large flat plains. For hydropower, it will primarily be proximity to water resources, including rivers and the ocean.

Thermal resources are relevant to higher latitude areas where heating is needed for comfort. Biomass can potentially be developed wherever a fuel crop can be raised, though most existing projects have been developed in areas where there is forestry activity and the wood waste provides a cost-effective fuel supply. Fuel cells and storage technologies are a potential supplement to a renewable energy project that can enhance reliability and timely supply of energy. While these technologies are not particularly impacted by climate, equipment may need to be kept cool to maximize performance and equipment life.

States will need to review with the civil aviation authority extended development plans to ensure that renewable energy projects do not impede future aviation-related development. An assessment of available property can identify underutilized lands suitable for renewable energy development. Planning can also consider how renewable energy could be incorporated into future development and thereby minimize the costs where shared infrastructure can be identified.

3.3.2 PROJECT CONCEPT

Using information on existing conditions, a project concept can be developed and feasibility determined. The site-specific issues described above should be considered in order to support an informed evaluation of what type of renewable energy project is appropriate, given site conditions, objectives, the regulatory landscape, and available resources.

Using the geography and climate conditions described above, the most feasible renewable energy technology can be identified. Solar is an option for most airports due to the open nature of the airport and the ability to site a solar project within the airport landscape. However, the amount of electricity produced by solar will be influenced by the site's location proximate to the equator and typical weather patterns, including an evaluation of precipitation events. Locations closest to the equator in relatively dry climates will maximize electricity production. Locations farthest from the equator, with cloudy or rainy conditions, will have the lowest electricity production efficiencies. The world insolation map provided as Figure 2-10 shows the regions of the world that have the best solar generation potential. Other renewable energy technologies are more specific to the project site and proximity to a resource (e.g., forested areas for biomass or water resources for hydro).

A fundamental consideration once the renewable energy technology is confirmed is to ensure that the project is compatible with aviation safety. Tall structures near airports can present a safety risk by impinging into airspace. In this regard, solar is generally compatible with airport operations, given its low profile where wind turbines must be tall to capture sufficient wind energy. Other technologies are either integrated into buildings (biomass) or underground (geothermal) and can be integrated into the aviation landscape.

Other potential aviation safety impacts like radar interference and glare must be avoided through appropriate siting analysis. For example, use of the SGHAT developed by the U.S. FAA can assess the potential for glare to impact controllers in the tower or pilots on final descent. Projects must meet ICAO Standards, and relevant ICAO guidance material is included in ICAO Doc 9184, *Airport Planning Manual*, Part 1.

Another key factor in siting a renewable energy project is the proximity of the project site to electrical infrastructure with sufficient capacity to receive the power. The project's financial feasibility will likely be tied to the costs to construct and interconnect the facility to the existing electrical network. A primary goal should be to identify a location where electrical interconnection upgrades are limited.

At many airports, the terminal is likely to be serviced by an electrical line capable of receiving electricity produced by an on-site renewable energy project. The members of the design team would need to identify a vault, transformer, or meter where the project could be physically interconnected to the existing system. The capacity of the electrical line may limit how much power can be delivered to the existing system. The project team will want to consult owners and operators of the grid system to confirm compatibility.

Once the airport has conceptualized the project, the next step is to identify potential project financing options.

4.0 PROJECT FINANCING

There are a number of ways an airport renewable energy project could be financed. A detailed presentation of financing low carbon technologies at airports is included in a separate guidance document prepared by ICAO that complements this guidance. This section provides an overview of central financing options applicable to renewable energy projects at airports.

How an airport solar project is financed is primarily reliant on two factors: who owns the project and how the electricity is purchased. The two fundamental ownership options are airport owned and third party owned. In either case, the owner must fund the project construction and as a result, assumes the project risk. However, by controlling the project funding and development, the owner also controls all of the associated benefits.

The purchasing scenarios are also divided between two primary options: airport purchase (airport owned) and non-airport purchaser (third party owned). In the airport purchasing option, the airport consumes the renewable energy benefits of the project either through direct on-site use (see net energy metering), or through executing a PPA with the third party owner. Where the airport is not purchasing the power, another purchaser, like the utility or for example a university, is acquiring the electricity through a PPA. In all scenarios, project financing cannot be readily secured until a buyer for the electricity is finalized. **Figure 4-1** illustrates the two airport renewable energy financing options.

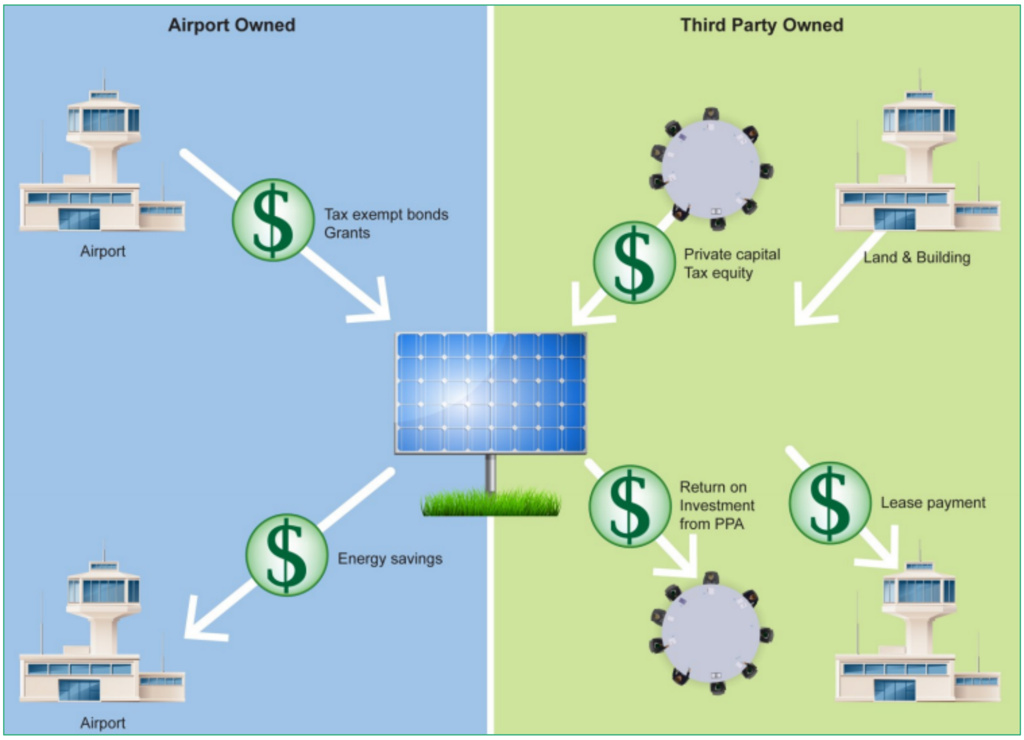

FIGURE 4-1
Airport renewable energy financing options (source: author)

The following sections describe three different development scenarios, including 1) airport owned and net metered; 2) third party owned and grid purchased; and 3) third party owned and airport purchased.

4.1 AIRPORT OWNED, NET-METERED

In the airport owned, net-metered scenario, the airport builds, owns and operates the renewable energy facility and uses the power directly on-site. The airport must raise the money to pay for the system through government sources, grants, and revenues from service fees.

Once the renewable energy system is paid for and is generating electricity that is consumed on-site, the airport's financial benefits are measured by the savings from not purchasing electricity from the national grid. If the airport uses all of the electricity generated from the facility on-site, the airport will save a sum of money based on how much it would have paid the grid operator for the electricity. If the airport uses only a portion of the electricity and exports the remainder to the grid, then the airport will save on its electricity bill an amount equal to the value of the electricity that it otherwise would have purchased, plus the value of the surplus electricity paid for the portion that was exported. The pay back will be reached sooner if the grid operator pays the airport a higher price for the electricity exported to the grid.

Airports should consider an airport owned model when the private market drivers for renewable energy are lacking. This condition primarily exists in developing countries. The airport owned model will be enhanced where development aid is provided to fund project construction. Examples of airport renewable energy projects owned by airports with funding provided by public or not-for-profit organizations include the solar at-gate projects constructed under the ICAO-UNDP and the ICAO-EU joint assistance projects. Other examples included in Section 6 that are airport owned with funding provided by government or aid organizations include the Palau Airport Solar Project and the Yellowknife Airport Biomass Project.

4.2 THIRD PARTY OWNED, GRID PURCHASED

In the third party owned, grid purchased scenario, the airport leases land to the third party developer who builds, owns and operates the renewable energy system and sells the electricity to an off-site customer. The third party finances the construction of the project primarily through equity and debt backed by the executed power contract with the electricity buyer. The airport acts only as a landlord and negotiates a monthly lease fee from the developer for the right to use airport land. These lease arrangements typically only work where the lease rate is low, as the developer could likely find an alternative site for the project unless the airport has some unique siting advantage.

Potential buyers of the electricity may include the grid operator, government, a university, or a private company. Buyers seek to purchase the electricity through a long-term contract for a number of reasons. First, government policy or laws may set renewable energy purchasing goals on electric utilities or on government entities. Second, their constituents may call for the organization to purchase renewable energy in support of government policies, which may be the case for a university, as an example. Third, some private entities may wish to execute a long-term contract (up to 25 years for some renewable energy sources), which establishes the price of electricity at a flat or relatively stable rate (e.g., escalating with inflation) over the term of the contract. This can be a hedge protecting the organization from future spikes in energy prices.

This business structure may be an option only in countries where there is a private market for renewable energy. Airports should consider this model when they are approached by a private developer, but should seek to limit their commitment to the project. Examples of this type of project are mostly represented in the United States, including the project at Indianapolis Airport.

4.3 THIRD PARTY OWNED, AIRPORT PURCHASED

Similar to the scenario above is the third party owned, airport purchased scenario. As above, the third party develops the renewable energy project on airport property. In this case however, the owner executes a long-term contract with the airport to purchase the electricity produced. This is a preferred scenario for the developer because they can go through a bidding process to obtain a site and sell power under a long-term contract and guarantee both ownership rights and secure a purchase contract. In this scenario, the land lease becomes essentially part of the power contract, as increasing the lease rate only increases the cost of the electricity paid by the airport. The airport may be motivated by the same reasons as stated above for pursuing a long-term contact for renewable energy, namely to meet certain public policy renewable energy purchasing goals and to mitigate risks associated with long-term electricity prices.

As with the model described above, this scenario will only be an option where there is a private market driver for renewable energy. The driver may be a policy incentive, such as a FIT. Such a policy programme provides an incentive for the airport to purchase the power produced by the project. Examples of projects where the renewable energy facility is owned by a private developer and the airport purchases the power through a PPA include Karratha Airport in Australia[52] and Kuala Lumpur Airport in Malaysia.[53]

5.0 EXAMPLE OF HOW TO PLAN AN AIRPORT SOLAR PROJECT

Solar has been the most successful renewable energy technology deployed at airports. This is largely in part due to the ability to integrate it into the airport's development profile without impacting aviation activities. The growth of airport solar projects has largely tracked the growth in the global solar industry, which has resulted in decreasing costs and increasing efficiency. This chapter presents an example of solar power project to provide the reader with a methodology for planning and implementing a renewable energy project at an airport. While the specifics of the example may not be applicable to all airports, it provides a methodology that can be followed to identify information needs and address project development issues common to all potential renewable energy projects at airports.

5.1 PLAN THE PROJECT

With the development of ICAO State Action Plans, many airports have identified renewable energy as a potential solution to help meet their carbon emissions reduction goals. The airport must then proceed along a systematic approach to planning and financing a project that is consistent with its long-term goals.

5.1.1 DEFINE THE PROJECT OBJECTIVES

There are many project objectives that may serve the airport's needs. For projects that seek to mitigate international aviation emissions, the airport will want to include gate electrification components and solar. Battery storage may also be added to ensure maximum use of solar power at the gate, as in the case of the ICAO-EU project at Moi International Airport in Mombasa, Kenya. For projects that seek to meet domestic emissions reduction goals, the solar project may be sized to maximize the amount of solar electricity used at the airport. If showing leadership in renewables is critical to the airport, the project site may be identified as being central to the airport terminal and visible to travellers.

5.1.2 IDENTIFY REGULATORY BARRIERS

The airport will need to communicate with the ministry of energy and the national electric utility to understand how potential regulatory barriers and incentives may affect project development. The airport will want to know if there are energy policies, like a FIT, that would benefit the proposed project. It is also important to understand the net metering policy and if surplus energy can be exported to the national grid, and what price the airport might receive for the electricity generated. The availability of tax incentives and PPAs may also determine if the solar energy private sector may be attracted to a project at the airport.

5.1.3 EVALUATING SITE CONDITIONS

The airport will need to consider its size and uses when evaluating a potential solar project. Large airports with a high energy demand will be able to plan for a large or small project with surety that the energy can be used, without concern for constraints like net metering compensation. Smaller airports may be limited by the availability of energy incentives as to project size where States with programmes that allow the airport to export surplus energy providing greater opportunity. In addition, large airports may be physically constrained by land, whereas smaller airports may have land available, thus increasing their options. Most airports can use solar energy; however, it will be important for assessing project economics to estimate the amount of energy produced by a system specific to the site location. The airport will want to consider existing electricity costs to determine what energy price would be needed to achieve cost-effectiveness.

5.1.4 SELECT THE TECHNOLOGY

The airport will review its project site for applicability of technology. In this example, the airport is neither close to a water resource, nor is it close to heat sources near the earth's surface, eliminating the options of hydroelectric and geothermal. It is difficult to know if there are sufficient wind resources on-site without erecting a meteorological test tower. The airport is in a relatively urban area and planners are not confident that there is sufficient buffer area to install a wind turbine. The project site is in the lower latitudes close to the equator and receives excellent solar resources. Based on this review of available technologies, the airport decides to pursue a solar PV project.

5.1.5 SELECT THE SITE

As described above, the airport, in this example, is in an urbanized region just outside a large metropolitan area. It consumes a significant amount of electricity, which is supplied by a relatively robust electrical network. The airport has some airfield areas that are not suitable for aeronautical uses because they are remote and distant from the main terminal. It will also take a fairly long electrical line to deliver power from the remote airfield to the existing electrical lines with sufficient capacity. The area near the terminal is built up and there are no unused areas that could be designated for solar. However, there are some surface parking facilities where solar canopies could be installed. This design would meet the need of being close to the main electrical lines, while also providing covered parking and a visible location for the solar project to demonstrate the airport's environmental commitment.

5.1.6 PREPARE FINANCIAL ANALYSIS OF OPTIONS

In this case, the airport runs the proposed project through three financial analyses. The first looks at transmitting the power directly to the airport behind the meter to feed the airport's consumption. The second looks at the options of leasing the parking lot area to a third party who will build, own and operate the solar project. The third determines the price of power produced by the third party project and compares it to the airport's existing and future electricity prices to determine if it would be economical for the airport to execute a long-term contract to buy the electricity output. The airport determines that the first option is best because the airport can consume most of the electricity and if it must export power at any time, the grid operator will pay the airport the retail price for any surplus electricity.

5.1.7 PREPARE AND OBTAIN APPROVAL FOR BUDGET

The airport estimates the cost of the solar panels, canopy structures and electrical upgrades and includes it in the next airport budget up for consideration. As part of the budget discussion, the airport provides an analysis of the costs, bonding needs and grants for installing the project, and an estimate of payback period for the system, assuming current electricity costs with an annual escalator.

5.2 ISSUE A TENDER

As the majority of airports are operated by public entities or otherwise control public infrastructure and oftentimes use public funds, work on airport property is typically subject to a public tender process. The airport coordinates with its engineering staff and existing consultant team to prepare a tender for an EPC (engineering, procurement, and construction) contractor who will procure the equipment and install the project.

5.2.1 PREPARE TECHNICAL SPECIFICATIONS AND BIDDERS LIST

The airport will prepare the technical specifications which describe the technical aspects of the project and the standards must be met. It will include project location, size of project in terms of nameplate electrical capacity, project components, applicable standards that the equipment and installation must meet, including those of the International Electrotechnical Commission (IEC), minimum warrantee requirements, and required bidder qualifications. The airport will also want to develop a bidders list to ensure that qualified firms directly receive a copy of the tender and evaluation criteria that can be used to impartially review and evaluate the bids.

5.2.2 ADVERTISE THE TENDER AND SELECT THE BEST BID

Once the technical specifications have been approved, the tender can be advertised. Notice should be placed as broadly as possible to maximize exposure of the opportunity and attract the most qualified bidders pool. The airport should convene a bidders technical meeting to review the tender and collect questions and prepare answers. Formal answers should be requested in writing. After receipt of all questions, the airport should prepare written answers to all questions and post them for all bidders to review. The airport should assemble a committee to review and rank the proposals based on the evaluation criteria developed as part of the bid. The review committee should rank the proposals based on the completed evaluation criteria and issue a notice of selection to the top ranked contractor.

5.2.3 NEGOTIATE CONTRACT AND PREPARE PROJECT SCHEDULE

Once the contractor is selected, the airport will negotiate the final contract including modifying the proposal based on new information if necessary. The airport will want to obtain proof of insurance and any other surety required in the contract. The bidder will also prepare a project schedule to guide the project implementation.

5.3 CONSTRUCT THE PROJECT

The project construction phase includes preparation of engineering plans, securing regulatory approvals and constructing the project.

5.3.1 SECURE REGULATORY APPROVALS

The airport will submit permit applications to local, state/provincial, and national authorities for permits authorizing the work. Such approvals will vary by location, but may include those necessary for local health and building codes, environmental protection, and electrical code compliance. The airport will also work with the national grid operator to ensure that the proposed project meets the interconnection requirements and various safety and security standards.

5.3.2 OBTAIN FINAL ENGINEERING PLANS

The contractor will prepare engineering plans based on those provided in the tender and comments from the airport. The engineering plans must be reviewed and approved by the airport and its team in order for the project to proceed toward the construction phase.

5.3.3 CONSTRUCT THE PROJECT

Project construction will include installing the solar canopy structures, installing the solar panels and inverters, and burying the electrical lines from the solar project to the applicable meter associated with the terminal building or other appropriate interconnection site. The equipment must be delivered to the site. Construction activities need to be coordinated locally with the airport to ensure that it does not interfere with regular airport activities. Regular construction meetings may be useful to track construction progress depending on the size and complexity of the project.

5.4 COMMISSION AND MONITOR

Once the project has been completed, the contractor will work with a competent third party to test the system to ensure that it will operate in a safe and secure manner consistent with the electrical grid, and performs as designed. Testing will be coordinated closely with the grid operator. Upon completion of the commissioning process, the project will be energized and commence operation. The contactor may also install a public display kiosk with educational material to provide the public with information about the project and its benefits. Software will also be included that will allow airport personnel and other technicians to review and monitor the project from a remote location to ensure its performance.

6.0 AIRPORT RENEWABLE ENERGY CASE STUDIES

Airports around the world have deployed renewable energy to generate on-site power. Carbon emissions reduction is most frequently identified as a primary factor for developing such projects. Beyond that overarching driver, airports have pursued project development influenced by geography, available resources, and opportunity. The following renewable energy case studies provide insight into what individual airports have accomplished, and how.

6.1 SEYMOUR AIRPORT, GALAPAGOS, ECUADOR, SOLAR AND WIND POWER

Seymour Airport, operated by the Argentinian company Ecogal S.A., is believed to be the only airport in the world working exclusively on wind and solar energy. Located on Baltra Island, one of 18 in the Galapagos archipelago, the airport consumes 35 per cent of its energy demand from solar PV panels installed on the terminal walkways and 65 per cent from wind turbine generators (WTG) located on the island. There are three WTGs, rated at 750 kW each, which supply electricity to the airport as well as to the town of Puerto Ayora on Santa Cruz Island which is connected to the wind project. **Figure 6-1** shows the airport and some of its renewable energy components.

The airport terminal building, 6,000 square meters of space, opened in 2012 at a cost of $40 million. It was constructed of recycled and sustainable materials and earned Leadership in Energy and Environmental Design (LEED) Gold-level certification in 2014. The building design maximizes natural light and cooling from ocean breezes with supplemental energy supplied by the renewable energy systems.

FIGURE 6-1
Seymour airport's wind turbines and solar panels atop walkway canopies (source: Ecogal S.A)

6.2 EAST MIDLANDS AIRPORT, UNITED KINGDOM, WIND POWER AND BIOMASS

The Manchester Airport Group (MAG) operates four airports in the United Kingdom: Stanstead, Bournemouth, East Midlands, and Manchester. MAG has set ambitious goals for carbon neutrality for each airport and first implemented its programme and achieved its goal at East Midlands.

While much of the carbon neutrality objective is met through the purchase of renewable energy from off-site generators, MAG has also developed renewable energy projects at each of its projects as a visible demonstration of its climate mitigation commitment. This is particularly true at East Midlands Airport, which is home to two large WTGs on airport property (see **Figure 6-2**). Installed in 2012, the WTGs rise 45 metres above ground, making them the tallest wind power structures on airport property in the world. The WTGs have a nameplate capacity of 250 kW each and produce electricity sufficient to meet approximately 6 per cent of the airport terminals needs. By consuming wind power and not buying the equivalent amount of electricity from the national grid, the airport is avoiding approximately 300,000 tonnes of CO_2 emissions annually.

FIGURE 6-2
One of two wind turbine generators at East Midlands airport (source: Manchester Airports Group)

MAG also raises crops which it burns in a biomass fired HVAC system used in the airport terminal. It grows willow trees on a 25-hectare plot of airport property as a fuel source. The willow is fast growing, allowing the airport to cut and use the crop over the entire area in a three-year cycle. The project avoids traditional heating and cooling power which would emit an additional 280 tonnes of CO_2 annually.

6.3 GEORGE AIRPORT, SOUTH AFRICA, SOLAR POWER

In September 2015, George Airport became the first airport in Africa to receive power from on-site renewable energy. The solar farm is situated next to the airport on an area of 1.2 hectares. The facility is comprised of 3,000 photovoltaic modules, with a nameplate capacity of 750 kW. It will supply electricity to meet 41 per cent of the airport's electricity needs. **Figure 6-3** shows part of the proposed project at the airport.

Located halfway between Cape Town and Port Elizabeth, George Airport lies in the heart of the scenic Garden Route, famous for its lush vegetation and lagoons which are dotted along the landscape. It handles over 600,000 passengers a year, many of them tourists, but it is also a national distribution hub for cargo such as flowers, fish, oysters, herbs and ferns.

The project was developed by the Airports Company of South Africa (ACSA) at a cost of just over $1 million to build, and is part of South Africa's commitment to introduce a mix of energy sources to all its airports. ACSA expects the facility to pay itself back in 20 years. The George Airport project is the latest in a string of alternative energy investments designed to help relieve the burden of irregular electricity supply, which has long plagued parts of Africa. ACSA has announced plans to install renewable energy at each of the five other regional airports in the country, followed by the three largest airports.

FIGURE 6-3
Solar project at George Airport in South Africa (source: Yeni Safak)

6.4 YELLOWKNIFE AIRPORT, CANADA, BIOMASS

In 2012, a 540 kW wood pellet boiler was installed in the Combined Services Building at Yellowknife Airport. The project was funded by the Northwest Territories Provincial Government (GNWT) as part of a broader programme to convert energy systems in public buildings to renewable biomass. The project avoids the combustion of approximately 256,000 litres of heating oil, saving the province $130,000 and offsetting 450 tonnes of carbon emissions annually.

Through 2015, GNWT has built 22 projects including a second airport project at Norman Wells. These projects have created a market demand for wood pellets, which is leading to the adoption of systems in the private sector as well.

FIGURE 6-4
Biomass fuel storage and boiler at Yellowknife airport (source: Government of the Northwest Territories)

6.5 STOCKHOLM-ARLANDA AIRPORT, SWEDEN, GEOTHERMAL HEAT PUMP/BIOFUEL

Stockholm-Arlanda Airport is the size of a small city of 25,000 people and its 500,000 square meters of building space is heated and cooled by renewable thermal energy. This is accomplished through a geothermal heat pump and biofuel district energy system.

The geothermal heat pump system uses the storage capabilities of an underground lake, or “aquifer”, to provide energy. When in operation, the heat pump system creates a warm side and a cool side in the aquifer. In summer, cool water is withdrawn and passed through a heat exchanger which further cools the water, and creates a byproduct of heated water. The cool water is delivered to each building through the district energy system and the heated byproduct is discharged to the heated side of the aquifer. In winter, the pumping is reversed with the heated water withdrawn and delivered to the district energy system while the cool water byproduct is discharged back to the cool side of the aquifer. This process is illustrated in **Figure 6-5**.

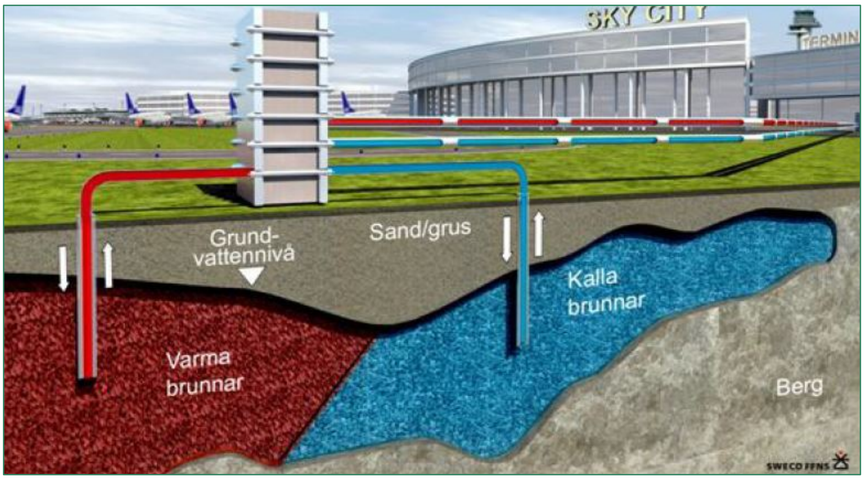

FIGURE 6-5
Geothermal heat pump system at Stockholm Arlanda airport (source: SPECIAL a European Union Partnership)

The system is balanced such that the aquifer provides all cooling in summer, but only pre-heat in winter. Finish heating is achieved with a biofuel fired facility.

The aquifer has reduced the airport’s annual electricity consumption by 4 GWh and its district heating consumption by about 15 GWh which is equivalent to the energy use of about 2,000 Swedish homes. Avoidance of CO_2 emissions is estimated to be 7,000 tonnes annually.

6.6 PALAU INTERNATIONAL AIRPORT, MICRONESIA, SOLAR

The government of Palau has overseen construction of a 226 kW solar facility at the Palau International Airport, funded by the government of Japan's Official Development Assistance (ODA) office. The project is comprised of 1,080 solar panels placed on canopies installed over the surface parking area adjacent to the airport to provide both electricity and shading. The canopy design took into account the potential for typhoon weather conditions and included enhanced stabilization. The project provides approximately 15 per cent of the electricity needs of the airport and offsets 80 tonnes of CO_2 annually. **Figure 6-6** shows the layout of the system.

FIGURE 6-6
Palau international airport solar facility (source: Solar Feeds)

6.7 SAN DIEGO INTERNATIONAL AIRPORT, UNITED STATES, SOLAR

The San Diego County Regional Airport Authority (SDCRAA) executed an agreement with a private third party which built, owns, and operates solar facilities associated with Terminal 2, and the airport purchases the power generated through a long-term contract, or PPA. The project was developed in three phases: (1) rooftop facility of 650 kW on the new wing on Terminal 2; (2) carport structures totalling 2 MW over surface parking adjacent to Terminal 2; and (3) a rooftop facility of 650 kW over the older wing of Terminal 2 once roof repairs are made. Through the purchase, the airport acquires the electricity and the environmental attributes which include the RECs, emissions reductions, and carbon offset credits.

FIGURE 6-7
Solar project at San Diego international airport (source: San Diego County Airport Authority)

6.8 KANSAI INTERNATIONAL AIRPORT, JAPAN, SOLAR AND WIND

The Kansai International Airport in Osaka, Japan has developed multiple renewable energy projects. In 2014, it initiated an 11.6 MW CIS (copper, indium, selenium) installation. The project uses CIS thin-film modules which are sited as two separate solar systems: one beside the airport's B runway and the other on a cargo warehouse (as seen in **Figure 6-8**). The system generates approximately 12 million kWh of electricity annually.

FIGURE 6-8
Kansai international airport solar facility on cargo warehouse (source: Solar Frontier)

In September 2015, Kansai also installed two Zephyr9000 wind turbines combined with a 50kWh battery bank. The Zephyr9000 is a 5.5m diameter wind turbine with an annual output of 8,809 kWh at 5m/s mean annual wind speed (see **Figure 6-9**). The system normally provides power for illumination, but can also provide emergency power.

FIGURE 6-9
Wind turbines at Kansai international airport (source: Zephyr Corporation)

CONCLUDING SUMMARY

ICAO Member States are developing and implementing State Action Plans to reduce their international aviation emissions. As part of the planning process, States are analysing the basket of measures available to reach their emissions reduction goals. Renewable energy offers States a great opportunity to mitigate CO_2 emissions from the aviation sector.

ICAO has prepared this guidance document to assist Member States with the evaluation of renewable energy as an opportunity to reduce international aviation emissions and improve local air quality. Depending on the project design, Member States may also achieve greater emissions reductions associated with aviation energy use from aircraft and airport activities. The examples presented in this guidance document demonstrate that civil aviation authorities and airports are working together to build successful renewable energy projects.

In its 2016 Medium-Term Report on Renewable Energy, the IEA stated that renewable power accounted for more than half of the world's additional electricity capacity in 2015 as the result of supportive government policies and sharp cost reductions.[5] Pioneering airports across the globe have participated in this growth through the successful deployment of renewable energy at airports. As renewable energy systems have become increasingly economical to deploy, and airports and their stakeholders have become more aware of the economic, environmental and social benefits that renewable energy provides, this growth in the deployment renewable energy has continued. The demonstration of solar at-gate projects in ICAOs assistance project participant States (Cameroon, Jamaica, and Kenya) are important pilot projects that can be replicated in other States and provides a clear step towards ICAO's primary environmental objective of reducing emissions from international aviation. The experience presented throughout this guidance demonstrates that renewable energy projects can be successful and easily replicable.

While each State and airport faces different challenges and opportunities, this report provides information on implementing various types of renewable energy, including solar power, which is highly compatible with many airports. This guidance material provides information on: how energy is consumed during aviation activities; existing renewable energy technologies and their use; issues to consider in project conceptualization; options for financing project development; the fundamental steps for planning and developing a renewable energy project, and provides a summary of several project examples from existing airports worldwide. It also provides States with insight into the process to implement renewable energy and their potential benefits for long-term sustainable growth in the international aviation sector. This guidance shows that developing airport renewable energy projects can also minimize CO_2 from activities at airports beyond those that relate to international civil aviation. Renewable energy can also be a key component of facility modernization and economic development.

This guidance is part of a series of guidance documents developed as part of the capacity-building and assistance project implemented by ICAO, in cooperation with the UNDP, with financing from the GEF. Within the series are other guidance documents on *Sustainable Aviation Fuels*, *Financing Aviation Emissions Reductions*, and *Regulatory and Organizational Framework to Address Aviation Emissions*, which all contribute to ICAO's comprehensive approach to support its Member States in the implementation of their Action Plans to address CO_2 emissions form international civil aviation, consistent with the United Nation's Sustainable Development Goals.

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